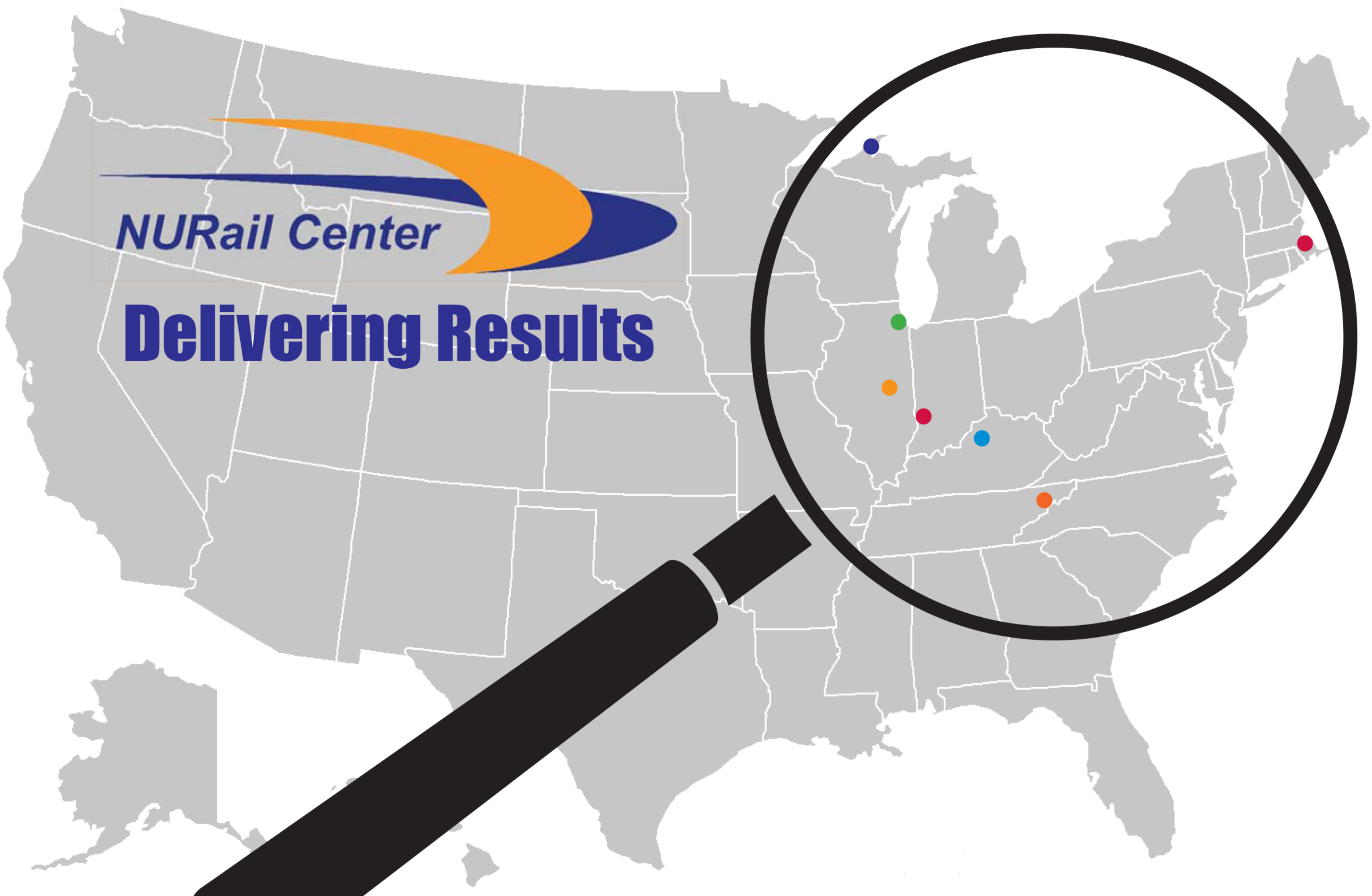
National University Rail Center
2015 Annual Meeting



University of Illinois at Urbana-Champaign
University of Illinois at Chicago
Massachusetts Institute of Technology
Michigan Technological University
University of Kentucky
University of Tennessee, Knoxville
Rose-Hulman Institute of Technology

Rail Focused US DOT OST-R Tier 1 University Transportation Center

Table of Contents

NURail Annual Meeting Agenda – June 3 - 4, 2015

University of Illinois at Chicago
Student Center West
Thompson Rooms - 2nd Floor
828 S. Wolcott Avenue
Chicago, IL 60612

Theme: Delivering Results

Wednesday, June 3rd

8:30am — Tour of Metra/Amtrak Operations Center – Preregistration Required
(Jody Plahm, UIC, and Greg Godfrey, Amtrak)

9:30am — Tour of Metra/Amtrak Operations Center – Preregistration Required
(Jody Plahm, UIC, and Greg Godfrey, Amtrak)

11:00 – 7:00pm — Registration (UIC Student Center West - 2nd Floor Lobby)

1:00 – 1:30pm — Student Leadership Council meeting (Room 206AB)
Tyler Dick, UIUC (Moderator)

NURail Affiliate Member Presentation (Room Thompson A)
Pasi Lautala, Michigan Tech (Moderator)
Dimitris Rizos, University of South Carolina (Moderator)

1:30 – 3:00 — Technical Advisory Committee discussion (Room Thompson A)
Conrad Ruppert, UIUC (Moderator)

3:00 – 3:15 — Break (2nd Floor Lobby)

3:15 – 4:30 — Improving Student Placement in Rail Industry Discussion/Workshop (Room Thompson A)
David Clarke, UTK (Moderator)

4:30 – 5:30 SDP breakouts/workshops

1. *Vehicle – Track Interaction – Room 204*
   Conrad Ruppert, UIUC (Moderator)
2. *Safety and Risk – Room 206AB*
   Rapik Saat, UIUC (Moderator)
3. *Network Capacity Planning – Room 213AB*
   David Clarke, UTK (Moderator)
4. *Urban, Regional and HSR Passenger & Funding and Economic Development – Room 216AB*
   Stephen Schlickman, UIC (Moderator)
   Joseph Sussman, MIT (Moderator)
5. *Multimodal Freight Transport – Room Thompson A*
   Reginald Souleyrette, UK (Moderator)

5:30 – 6:00 SDP Wrap-up (Room Thompson A)
Conrad Ruppert, UIUC (Moderator)

6:00 Reception and Poster Session (Room Thompson C)

6:15 3-Minute Thesis Competition (Room Thompson C)
Conrad Ruppert, UIUC (Moderator)

7:00 Dinner and Keynote Address (Room Thompson B)
Keynote Speaker:
Dr. Mitra Dutta
Vice Chancellor for Research
Distinguished Professor, Electrical and Computer Engineering Department
University of Illinois at Chicago

Thursday, June 4th

7:00 – 9:00am Registration (UIC Student Center West – 2nd Floor Lobby)

7:00 – 7:30 Continental Breakfast (2nd Floor Lobby)

7:30 – 7:45 Welcoming Remarks (Room Thompson A)
Ahmed Shabana, UIC, and Steve Schlickman, UIC
Christopher Barkan, NURail Center Director, UIUC

7:45 – 8:30 Education Showcase: NURail Graduates in Action (Room Thompson A)

Placement statistics (NURail and non-NURail students)
Pasi Lautala, Michigan Tech (Moderator)

Student Testimonials and Panel Discussion
Michael McHenry, UK/TTC
Brandon Van Dyk, UIUC/Vossloh
Marcella Bondie, UIC-CUPPA
Joel Carlson, MIT/Consultant
Garrett Fullerton, UIUC/CN
Ahmed Aboubakr, UIC-COE/Gamma Technologies

8:30 – 9:30 Research Showcase: Part 1 (Room Thompson A)
Conrad Ruppert, UIUC (Moderator)

8:30 Craig Foster, UIC-COE
"Coupled Multibody and Finite Element Modeling for Simulating Vehicle-Track-Substructure Interaction"

8:50 Chen-Yu Lin and Rapik Saat, UIUC
"Shared Rail Corridor Adjacent Track Accident Risk Analysis"

9:10 Pasi Lautala and David Nelson, Michigan Tech
"Exposing Undergraduate Students for Railway Research/Development"

9:30 – 9:40 Group Photo (Courtyard to the west of the building)

9:40 – 10:00 Break (2nd Floor Lobby)

10:00 – 11:30 **Research Showcase: Part 2** (Room Thompson A)
Conrad Ruppert, UIUC (Moderator)

10:00 Reginald Souleyrette, UK
"Rail Crossing Improvement Strategies"
10:20 Joseph Sussman, MIT
"Rail as a Complex Sociotechnical System"
10:40 James Labelle, UIC-CUPPA
"Off Peak Delivery Project"
11:00 Asad Khattak, UTK
"Trespassing Crash Injury - Role of Pre-crash Behaviors"

11:30 – 12:30 **Lunch & NURail Partner Student Organization Highlights** (Room Thompson B)

Partner Student Organization Highlights
Tyler Dick, UIUC (Moderator)
NURail Student Leadership Council
Samuel Levy, MIT (Moderator)
Presentation on Student Collaboration
James O'Shea, UIC (Moderator)
Teng "Alex" Wang, UK (Moderator)

12:30 – 1:45 **Outreach, Workforce Development and Tech Transfer Showcase: NURail in Action** (Room Thompson A)
Christopher Barkan, NURail Center Director, UIUC (Moderator)

Company/Industry Testimonials and Panel Discussion
Doug Whitley, Supply Chain Innovation Network of Chicago
Robert VanderClute, Association of American Railroads
Ryan Kernes, GIC
Nikkie Johnson, Michigan DOT
Sergio "Satch" Pecori, Hanson Professional Services Inc.
Michael McLaughlin, Chicago Transit Authority
Vinaya "Vinny" Sharma, Sharma & Associates
Michael Franke, Amtrak

1:45 **Closing Remarks**
Christopher Barkan, NURail Center Director, UIUC

1:50 **General Public Adjourn**

2:00 – 2:30 **Executive Advisory Board Members – Closed Session** (Room 204)

2:00 – 2:30 **NURail Principal Investigators Meeting** (Room 206AB)

2:30 – 4:00 **Executive Advisory Board with NURail partners – Closed Session** (Room 206 AB)

University of Illinois at Urbana-Champaign

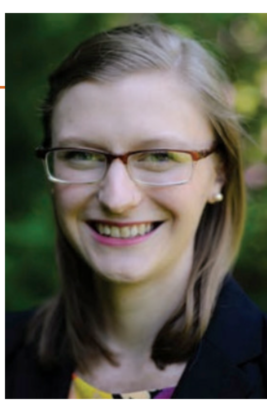
Henry Wolf '14

Henry Wolf is a Graduate Research Assistant with the Rail Transportation and Engineering Center (RailTEC) at the University of Illinois at Urbana-Champaign. He received his BS in Civil and Environmental Engineering from the University of Illinois at Urbana-Champaign in December 2013. He continued his studies at UIUC and is currently pursuing a Master's degree in Civil Engineering with a focus in structures. His research interests are focused on the flexural behavior of prestressed concrete monoblock crossties under varying ballast support conditions. His work has included analytical modelling and lab and field experimentation on concrete crossties. His main objective is to quantify bending moments experienced by concrete crossties in service and to use this information to improve current design practices in the AREMA Manual for Railway Engineering. He has enjoyed the collaboration of AREMA Committee 30 (Ties) and using the group's feedback to drive his work. He has presented his research at technical conferences and succesfully passed updates to the AREMA Manual. Henry is also interested in bridges, and hopes to translate his experience with prestressed concrete crossties to a career in bridge design.

Alexander Lovett '13

Originally from Albuquerque, NM, Alexander Lovett earned a B.S. degree at BYU in 2010 and an M.S. degree at UIUC in 2013 both in Civil Engineering. He is currently working on a joint MBA/Ph.D. at UIUC where his research focuses on optimizing railroad track maintenance. The combined business and engineering perspective of this degree will provide unique insight into railroad engineering. His research objectives include identifying and quantifying costs and benefits to performing maintenance. These can be used to objectively prioritize maintenance activities and select optimal maintenance activities for a specific area. He has presented his research at conferences and published his work in peer-reviewed journals. Alexander has served as treasurer of the treasurer of the AREMA Student Chapter at UIUC where he participated in educating students about possible careers in railway engineering.

He also teaches the Railroading merit badge, which includes teaching youth about the importance of the railroads and how to safely interact with them. He is a recipient of the Eisenhower Transportation Fellowship, which provides stipend and tuition assistance to transportation students in an effort to keep educated and motivated professionals in the transportation industry. After completing his degree, Alexander plans to work at a Class 1 railroad where he can continue improving the economics of railroad transportation, while being active in educating the community about railroads.

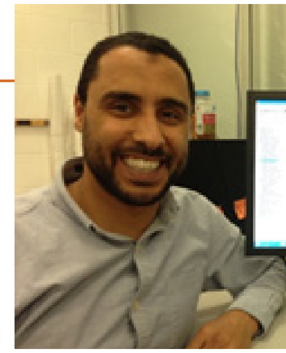


Samantha Chadwick '12

Originally from Shrewsbury, MA, Samantha Chadwick earned a Bachelor of Science degree in Civil Engineering at UIUC in December 2010. She is currently completing her Master of Science degree and thesis research at UIUC which focuses on understanding the effect of grade crossings on train safety and risk. The objectives of her research include identifying and understanding the physical factors leading to derailments at grade crossings, evaluating the risk, and prioritizing decisions to upgrade or close grade crossings. She has presented her research at conferences and published her work in a peer-reviewed journal. Samantha is past president of the AREMA Student Chapter at UIUC where she participated in outreach activities designed to educate students about possible careers in railway engineering and mentored engineering students through their curriculum. This effort reached students at four different universities and increased awareness of the benefits of railroad transportation. She recently was selected among 18 young scholars nationwide to be named a Luce Scholar. This highly-competitive program provides full stipends and internships for recipients to live and work in Asia to increase Asian awareness among future leaders in American society. Samantha's assignment will be in Taiwan. After completing her work abroad she plans to "lead the charge towards HSR in America" and further unlock transportation developments in commuter rail and subway networks in the United States.

University of Illinois at Chicago

Ahmed El-Ghandour '14



Ahmed El-Ghandour obtained his BS in Mechanical Engineering from Cairo University and his MS in Mechanical Engineering from UIC. He is now a PhD candidate in Civil Engineering at UIC. His work centers on the field of computational mechanics and Finite Elements.

Ahmed's experience has been developed through various projects including the work of NURail, where his focus is on the interaction between the rails and the substructure with special reference to soil settlement and bridge approach problems.

Ahmed polished his academic skills through practical internships at SHARMA & Associates and GE Global Research, where he worked on different projects using his railroad and computational mechanics knowledge. He has participated in several conferences to present his PhD work. Ahmed also holds a 3rd Dan Black belt in Taekwondo, and is a certified referee in both Egypt and USA.

Jenny Kane '13

Participation in transit-oriented research studies and time spent as a Congressional staff member have given Jenny Kane the practical skills and experience needed to pursue career aspirations in transportation project management. Starting in late 2013, Jenny participated in the "New Starts Ranking" research, a study to identify a method to rank proposed transit expansion projects in Northeast Illinois and nationwide.

The study, funded by the Illinois Department of Transportation, focuses on how other states and non-governmental organizations evaluate and prioritize capital projects. She also contributed to research on "Transit Value Capture," an effort to track and evaluate financing mechanisms between planners, taxing bodies and developers.

Jenny, who earned a Master's degree in Urban Planning and Policy from UIC, maintains that her years as a legislative aide on Capitol Hill–she served on the staffs of two members of Congress and a Senator–will prove valuable throughout her career. She is passionate about bike sharing, transit and inter-city passenger rail, and will tell anyone who will listen that Amtrak is the best way to see America.

James O'Shea '12

Originally from Shrewsbury, MA, James O'Shea earned Bachelor of Science and Master of Science degrees at UIC and is currently pursuing his Ph.D. in Mechanical Engineering. As an undergraduate he participated in internships and other programs with organizations such as Caterpillar and NASA Airborne Science where he began to develop a growing interest in vehicle dynamics.

James began to focus on rail research and is currently studying vehicle stability and wheel/rail interactions during derailment scenarios. He hopes to contribute to the analysis and prevention of vehicle derailments. James has presented his work at several conferences and some of this work has been published in ASME Transactions. He has also served as a reviewer of technical papers submitted to ASME conferences as well as IMechE and ASME Transactions.

Massachusetts Institute of Technology

Tolulope Ogunbekun '14

Tolulope Ogunbekun is a student in the MEng program in Civil and Environmental Engineering, specializing in transportation. She hails from Nigeria and first came to the U.S. for undergraduate studies at Mt. Holyoke. From there, Tolu moved into transportation consulting working for Steer, Davies, Gleave for three years. She decided to return to graduate school at MIT and joined the R/HSR Group. Tolu's research deals with the performance of Acela and regional services in the NEC, focusing on on-time performance. She is concerned with identifying the causes of schedule deviations and train cancellations. Further, she is considering the relationship between performance and market share using econometric techniques. Tolu will graduate in June 2015.

Ryan Westrom '13

Ryan is a second year Master of Science in Transportation (M.S.T.) student at the Massachusetts Institute of Technology. He grew up in the northwest corner of Minnesota, in Crookston. He has re-entered the academic world after over a decade spent working as an engineering and planning consultant for Patrick Engineering Inc. in Chicago. That work followed his undergraduate work at the University of Illinois at Urbana-Champaign (Class of 2001) where he received degrees in both Civil and Environmental Engineering and Urban and Regional Planning.

Ryan arrived at MIT in August 2012. He works in Professor Joseph Sussman's Regional Transportation Planning and High-Speed Rail Research Group and is focusing on issues of livability, sustainability, placemaking, and policymaking within the realm of regional transportation planning, urban centers, and integrated transportation and land use coordination. Topics of research exploration have included the future of transportation in an increasingly digital and urban world as well as local and regional impacts from large transportation infrastructure investments.

During his first summer term after beginning at MIT, Ryan worked at the Volpe National Transportation Systems Center,in Cambridge, MA for several months. There, he worked on a significant research project on the future of transportation. Ryan is currently completing work on his thesis, in which he is undertaking a comparative analysis of the impact of HSR on the cities of Coimbra and Leiria in Portugal and Champaign-Urbana and Kankakee in Illinois.

S. Joel Carlson '12

Originally from Prince Rupert, BC, Canada, S. Joel Carlson became interested in the transportation field while interning at the Prince Rupert Port Authority. Joel is a dual Master of Science in Transportation and Engineering Systems student and works in Joseph Sussman's Regional Transportation Planning and High-Speed Rail Research Group at MIT where he studies HSR using the CLIOS Process considering both institutional and technical issues. His research work focuses on the challenges of implementing HSR in the NEC using the CLIOS Process, along with scenario planning and real options analysis, to help characterize and manage the uncertainties associated with long-term planning.

During his first summer term after beginning at MIT, Joel worked for two months with the SNCF in Paris, France, where he was exposed to France's impressive efforts at making HSR an integral component to the overall transportation system. That same summer, he was also given a scholarship to attended UIC's 8th World Congress on HSR in Philadelphia, PA where he received second place for his essay submission to the conference.

Joel received his Bachelor of Science in Civil Engineering from the University of Alberta in 2011, where he received the Governor General's Silver Academic Medal, as well as the Rt. Hon. C.D. Howe Memorial Fellowship, the University of Alberta's highest monetary award for graduating students.

Michigan Technological University

Karl Warsinski ‘14

Karl Warsinski is a PhD candidate in the Materials Science and Engineering Department at Michigan Technological University. His career focus is in process metallurgy and casting development. Karl completed bachelor’s degrees in both Materials Science and Engineering and Civil Engineering at Michigan Tech in 2011, before continuing into the PhD program. His dissertation work is focused on the effects of alloy composition on thermal stability in austempered ductile iron.

Karl is actively involved in the student chapters of the American Foundry Society (AFS) and Material Advantage, as well as the Smithing Guild at Michigan Tech. To date, Karl has presented his work in the Joint Rail Conference. In addition to his work on ADI railroad wheels, he is also involved in a cast wheel bearing project sponsored by Amsted Rail.

Undergraduate Students Projects ‘13

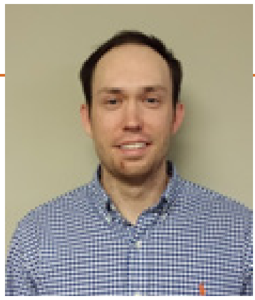
Externally funded research and projects conducted by undergraduate student groups are an important approach to engage and educate new students on rail transportation/engineering at Michigan Tech. Projects commonly last two academic semesters, have strict deliverable requirements, and are advised collaboratively by NURail/Michigan Tech faculty and industry stakeholders. In addition to tangible industry benefits in the form of new methods, designs, or tools, the projects result in collaboration across disciplines, and increased rail research exposure for students with practical and hands-on components, and recruicment opportunities for sponsoring agencies. Several student research projects were made possible by NURail and matching industry funding in 2013, ranging from development of a remote sand level sensor for locomotives (Union Pacific RR) to improvements in knuckle design of Type E coupler (Michigan Tech and Amsted Rail) and evaluation of grade crossing surface performance (Michigan Dept of Transportation). Shown in this picture is the Balise and Train Control System Market Study Team which was funded by NURail and the Tech Expert Network. From left to right are: Michael Roskelley (EE), James Shamel (EE), Ran Sui (EE), Yiheng Yan (EE) and Chuansheng Chang (EE).

Hamed Pouryousef ‘12

Hamed Pouryousef is a graduate student pursuing his Ph.D. in Civil and Environmental Engineering under the supervision of Pasi Lautala. Hamed earned a Bachelor of Science degree in Railroad Engineering from the Iran University of Science and Technology in 2001. He then joined Metra Consultant Engineers, affiliated with the Iran Department of Transportation, where he was involved in several rail and transportation projects for eight years before joining the Lisbon based MITPortugal Master of Science Program in 2008.

After graduation in 2010, Hamed moved to Michigan Tech. In addition to his research work on railway capacity, Hamed has been the technical lead to a federally funded project “HSR Workforce Development through Online Education and Training” and has been the instructor for the Rail Transportation Seminar course at Michigan Tech. Hamed is a member of TRB Committee AR060 (Railway Maintenance) and is an active AREMA student member in Committee 16 (Economics of Railway Engineering & Operations) and Committee 17 (High Speed Rail Systems) since 2010.

University of Kentucky



Brett Malloy '14

Brett Malloy received his M.S. degree in Civil Engineering (Transportation Emphasis) from the University of Kentucky in 2014. His research topic was "Railway/Highway At-Grade Crossing Surface Management". He is a native of Kentucky. While a student, Brett was an active member of the AREMA student chapter at UK (RailCats).

He was also a Provost Scholar, a member of the UK Honors Program and Phi Sigma Theta National Honor Society, and is presently an Engineer-in-Training with Integrated Engineering in Lexington, KY.

Alex Wang '13

Teng "Alex" Wang is a Ph.D. candidate in the Department of Civil Engineering at the University of Kentucky. Alex hails from the Gansu Province of western China where rail transportation is critical to economic development of the region. Alex's familiarity with the outstanding technologies being implemented today in China (Tibet railway, high-speed networks) is a real benefit to the UK team.

Alex received both his B.S. and M.S. in Civil Engineering from Iowa State University where he conducted research on transportation safety, planning, data and GIS applications. Today, his research focuses on railroad engineering, rail-highway grade crossing and remote sensing and image analysis by GIS. His dissertation relates to 3D methodology for evaluating rail crossing roughness, and is funded by the NURail Center and Kentucky Transportation Cabinet.

Alex served as President of the Transportation Student Association (TSA) and ITE student chapters at Iowa State University. Today Alex is an active member of several professional organizations and the AREMA student chapter at UK (RailCats).

Mike McHenry '12

Mike McHenry earned a Bachelor of Science degree in Civil Engineering at UK and is currently pursuing a Master of Science degree under the guidance of Jerry Rose with a focus on geotechnical and railroad engineering. His interest in railway engineering began in the front row of Professor Rose's Railway Engineering course in the spring of 2010 and soon after he became an undergraduate research assistant. His interest in track design and geotechnical engineering continued to grow, especially with regards to ballast fouling and railroad subgrade issues. His research seeks to develop a methodology to measure the pressure distribution at the interface of the tie and ballast.

With his unique interest in railway engineering and geotechnology, Mike was named a Dwight David Eisenhower Transportation Fellow and was also awarded a Wethington Fellowship from the University of Kentucky Graduate School. Mike is the founding president of RailCats, an AREMA student chapter at UK formed in 2011. He has also participated at national and international technical conferences, industry committee meetings, and a recent internship at the TTCI in Pueblo, CO.

University of Tennessee, Knoxville

Qiang Gui '14

Qiang Gui is a first-year doctoral student with a specialization in bridge seismic research at the University of Tennessee Knoxville (UTK). Before enrolling in UTK, he obtained his master's degree from the structural engineering department of Tianjin University, China in 2008 and had six years' industrial experience on railroad bridge engineering.

Qiang arrived at UTK in August 2014. He works on Professor John Ma's research team and is working on a NURail funded project "Seismic Evaluation of Existing Stone Masonry and Unreinforced Concrete Railroad Bridge Piers". Recently, he has started several preliminary works under guidance of Professor Ma and AREMA Committee 9 experts. In his first year at UTK, Qiang received the William H. Becker Memorial Scholarship from AREMA. He enjoys research and hopes to become a theoretical and experimental researcher on bridge engineering.

Yuan Jing '13

University of Tennessee Ph.D. student Yuan Jing earned her bachelor's degree in Highway Engineering at Chang'an University in July 2012. The Highway Engineering program at Chang'an University was ranked first among the universities in China. Yuan was awarded a scholarship every year during her undergraduate study. She participated in several educational competitions and activities during her study. She was also one of the top five students in her department to have the chance to do senior design at UTK from January to May in 2012.

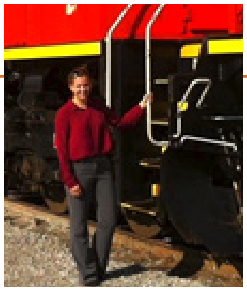
In August 2012, Yuan began her graduate study at UTK. Her research focused on lateral impact on hybrid composite beams by over-height vehicles. In April 2013, she presented her research work at the Joint Rail Conference. She was recently invited to the 2014 Joint Rail Conference to accept the 2014 ASME RTD Graduate Student Conference Scholarship for her written paper "Lateral Impact of Railroad Bridges with Hybrid Composite Beams." Yuan would like to be a university professor after getting her doctoral degree from UTK and believes that she could affect young people with her knowledge, skills, and overseas experience.

Ying Zhang '12

Ying Zhang started her Ph.D. study in August 2012 at UTK and was immediately involved in the railroad routing and capacity research funded by NURail. She is advised by Dr. Mingzhou Jin and affiliated with the Logistics, Transportation, and Supply Chain lab at UTK. She has finished the literature review of railroad capacity study. Based on the work of prior students in the lab, Ying has worked on algorithms to route rail traffic under congestions, which is critical to evaluate capacity of a railroad network. When a network is operated close to its capacity, the travel time on links and the volume at yards could be heavily impacted or limited.

Ying will present preliminary results at the Joint Rail Conference 2013 that will be held in April. In addition, she will submit another journal paper in Spring 2013. Ying received a Master's degree of Management Science and Engineering from Yanshan University in China in 2009 and a B.S. of Industrial Engineering from Tianjin University in China in 2006. She recieved the Excellent Graduate award by Yanshan University in 2008 and received the Outstanding Student Leader award and the Renmin Scholarship during her undergraduate study at Tianjin University.

Rose-Hulman Institute of Technology



Allison Phillips '14

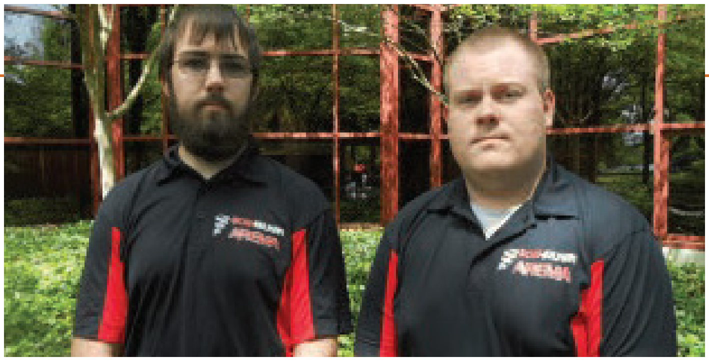
Allison Phillips is a sophomore Civil Engineering student from Mooresville, IN. She has held a long-time interest in transportation as well as historical and current railroad operations. Allison was awarded the 2014 Canadian National Diversity Scholarship and spent the summer of 2014 working as a Design and Construction intern for Canadian National in Homewood, IL. While there, she edited track charts, surveyed existing yard tracks and land for siding expansion, and examined track tie-plates for misaligned spikes.

Allison is the current Secretary/Treasurer of the Rose-Hulman AREMA student chapter. Allison is a second year member of the organization. She has been active in Rose-Hulman AREMA activities - recruiting new member at the annual campus wide activities fair, attending all field site visits, as well as all chapter meetings. She attended the 2013 AREMA Annual Conference in Indianapolis and the 2014 AREMA Annual Conference in Chicago. In addition to her AREMA duties Allison is the Fund Raising Manager for Engineers Without Borders; an active member of the Rose-Hulman ASCE student chapter; and a RHIT Homework Hotline Tutor.

Zach Ehlers '13

Zach Ehlers is a junior Civil Engineering student from Cullom, IL. A long time rail enthusiast, he quickly discovered that he could apply his interest to his degree. He spent the summer of 2013 as a NURail Center undergraduate intern at UIUC working on the concrete crosstie project. In addition to this work, he has been an active volunteer at the Illinois Railway Museum in Union, IL, where he works in the Electric Car Department and in Train Operations. He was awarded the 2013 AREMA Canadian National Railway Company Scholarship.

Zach is a founding member of the Rose-Hulman AREMA student chapter, where he currently serves as secretary and treasurer. Through the second year, the student chapter grew to 23 members. During 2013, seven chapter meetings and eight field trips (Norfolk Southern's Decatur shops, Indiana Railroad's Bear Run mine project, Canadian National's Kirk and Markham yards, and Amtrak's Beech Grove shops) were conducted. Twelve student members attended the 2013 AREMA Annual Conference in Indianapolis.



Greg Frech and Sam Beck '12

Greg French is a junior Civil Engineering student from Lake Zurich, IL. He spent the summer of 2012 as a NURail Center undergraduate intern at UIUC working on the concrete cross tie project. Greg will be interning in 2013 with the Mott and Nichol Rail Division in Raleigh, NC. He was awarded the 2013 AREMA Committee 27 - John Deere Scholarship.
Sam Beck is a junior Mechanical Engineering student from Hammond, IN. Sam interned at the Norfolk Southern's Portsmouth, OH car shop during the summer of 2012 and will return there in 2013. He is the author of the book The Indiana Harbor Belt Railroad in Color. Sam was awarded the 2013 AREMA President's Scholarship.

Greg and Sam are the founding officers of the Rose-Hulman AREMA student chapter with Greg serving as Chapter President and Sam serving as Chapter Vice President. Through their leadership, the student chapter grew to 17 members. They conducted seven monthly meetings and participated in seven railroad field trips/site visits which included the Wabash Valley Railroaders Museum; Indiana Harbor Belt Railroad; Amtrak Beech Grove Shop; Indiana Transportation Museum; Indiana Rail Road Hiawatha Yard; the Indiana Rail Road Indianapolis intermodal terminal; and an Indiana Rail Road rail sliding project.

Summer Youth Program in Rail and Intermodal Transportation

David Nelson, Michael Larson and Pasi Lautala, Michigan Technological University

For the past five years, Michigan Technological University has offered a Summer Youth Program (SYP) in Rail and Intermodal Transportation. The program, which hosts a diverse group of students in grades 9-11, has seen continuous growth. The structure of the program consists of classwork, tours, and hands-on activities. One student commented, "From what I have learned in the program, I am now interested in a future career with the industry."

History of the Program

The mission statement of the program is "a collaboration to attract a new generation." The Summer Youth Program at Michigan Tech has been a joint venture with the University of Wisconsin–Superior since 2010, and the program has seen continual growth (Figure 1). The growth has been especially strong in years 2013 and 2014 after the arrival of NURail funding. This funding increased the scholarship levels from the original 50% (graciously provided by industry partners) to 100% of the program fee.

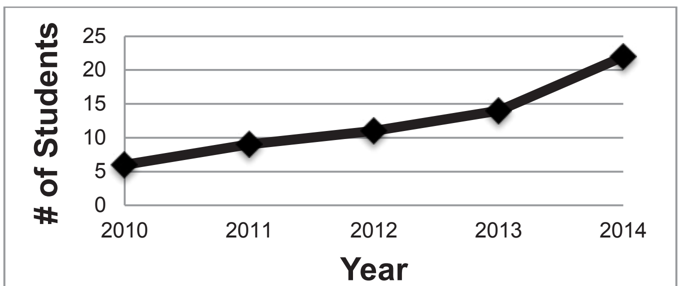


Figure 1. Continued increase in growth for Michigan Tech's SYP in Rail and Intermodal Transportation.

The 70 students that participated in the program came from 17 states (Figure 2). Over 20% of the participants were from minority populations, and nearly 10% were female students. In 2014, two minority students from Springfield, IL had their travel sponsored by Hanson Professional Services, in addition to the standard full scholarships.

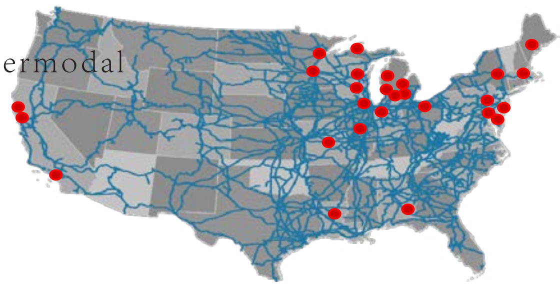


Figure 2. Participant hometowns throughout the U.S.

Program Topics and Activities

Over five program days, students learn in a variety of formats, but most of the program time is devoted to industry field trips and hands-on activities. Some of the core topics covered during the program include:

- Introduction to Rail Transportation
- Track Structure
- High Speed Rail
- Track Safety
- Rail Operations
- Supply Chain and Logistics Management
- Urban Transit
- Maglev systems

Hands-on activities include designing and constructing a scale model track section (Figure 3), operating a locomotive and train consist in a train simulator, and designing and racing maglev cars on a track layout.

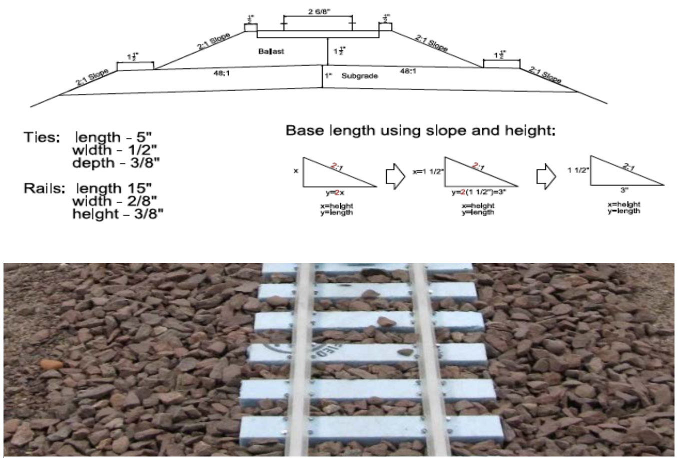


Figure 3. Track calculations and finished construction.

Thanks to industry support, students are provided with excellent opportunities to go on multiple field trips and see the industry in action. Industry professionals and their companies take time out of their workday to showcase their facilities to the students. Many students rank the field trips as the highlight of their week. With the diversity of the trips and the knowledge and passion communicated to the students by industry professionals, it is easy to understand why. Table 1 shows the 2014 program field trips.

Table 1. Field Trip Activities

Monday	Lake Superior and Ishpeming (LS&I) Railroad – car shop, terminal/yard, and visit to ore mine/docks
Tuesday	Travel to Superior, WI field visits
Wednesday	BNSF railyard – dispatch center, yard activities, car shop Halvor Lines – trucking dispatch and control, truck simulator, truck cab
Thursday	CN taconite dock, rail interface with Great Lakes shipping, North Shore Railroad Museum and train ride
Friday	Lake Linden and Torch Lake Railroad Museum

The LS&I trip to Ishpeming, MI on Monday afternoon included a quick tour of the mine facilities supported by the railroad. A program session on signals and rail safety was taught on the four-hour bus trip to Superior, WI. The tour of BNSF facilities in Superior gave the students another look at rail and yard operations on a much larger scale. The visit with Halvor Lines is a perennial favorite. Driving a truck through a tornado in the simulator (Figure 4) is always fun!


Figure 4. An SYP participant operates the Halvor Lines' truck simulator.

The CN taconite dock in Duluth demonstrated the connection and transloading process required to move iron ore from the mine to a ship by rail. The North Shore Museum stop (Figure 5) gave the students a chance to relax, unwind, and explore the history of the rail industry, including a ride in the tourist train.

Figure 5. SYP students at the North Shore Railroad Museum.

Upon completion of the program, students received a certificate to commemorate the week of fun-filled learning, hands-on activities, and industry tours. As usual, we expect some of them to return to Michigan Tech as undergraduate students.

Railroad Engineering Education Symposium (REES) 2012

Pasi Lautala and David Nelson, Michigan Technological University

The objective of the 2012 Railroad Engineering Education Symposium (REES) was to continue the work started at 2008 and 2010 REES events and to develop interest among university faculty in railroad transportation engineering, with the goal of facilitating and supporting their interest in adding railroad engineering content to their engineering courses and curricula. In 2012, the event was partially supported by the NURail grant and NURail members led the preparation and presentation of the course materials.

Symposium Overview

The American Railway Engineering and Maintenance-of-Way Association (AREMA) is the railway industry's professional organization that, among its other goals, promotes railway engineering education. In response to this challenge, AREMA's Education and Training Committee (Committee 24), in collaboration with the academic rail faculty, developed the Railway Engineering Education Symposium (REES) that is operated under the auspice of the AREMA Educational Foundation. REES is intended to foster the participation of university faculty in railway engineering with the goal of encouraging and supporting their interest in adding railway engineering content to their engineering courses and curricula. The inaugural REES was held in June 2008 at the University of Illinois at Urbana-Champaign in Urbana, Illinois. Since then, REES is held biannually.

REES 2012 was held June 11-13 in Overland Park, KS at the Johnson County Community College (JCCC). REES 2012 presented basic railway education materials, but also added more advanced material targeted toward professors who returned to REES to deepen their understanding of the railroad industry. The basic program was designated as REES 1, and the advanced program as REES 2. The topics covered in REES 1 and REES 2 are shown in the Table 1.

Table 1. REES 1 and REES 2 Topics

REES 1	REES 2
Intro Railroad Engineering	Vehicle Train Dynamics
Intro Railroad Infrastructure	Train Performance
Train Energy, Power, & Traffic Control	Advanced Train Control
Railroad Intermodal Transportation	Intro Railroad Capacity
Transit Commuter Intercity Rail Transportation	High Speed Rail Planning
Railroad Alignment Design & Geometry	Railroad Engineerng Software
Railroad Engineering Design Case Studies	Shared Corridor Challenges

In addition to academic modules, REES 2012 included sessions on the need for railway engineering education, workforce development issues, research programs and funding available for rail projects, and AREMA student chapters. William E. Van Trump provided a keynote address on 150 years of the Union Pacific railroad.

REES 2012 wrapped up with field trips. The main visit was organized to the BNSF Argentine Yard complex, where the group got to visit a yard tower, dispatching center, and gravity classification yard. The participants also had an opportunity to tour the BNSF training facilities located on the Johnson County Community College campus.

The event was a true collaboration between AREMA and academia, especially NURail. REES covered most of the faculty participation expenses, courtesy of 23 rail industry companies who supported the event. On the academic side, a total of ten faculty, staff, and students from NURail universities presented as part of the program. A complete list of NURail and other instructors can be found on the AREMA website at https://www.arema.org/education/rees/index.aspx

Results

In total, 28 professors participated in the event, with 20 professors new to the program attending REES 1 and 8 professors returning for REES 2. Of the 28 individuals attending REES 2012, 8 represent universities that belong to the NURail Affiliate University Program. According to the latest statistics, 16 of the 28 schools represented at REES 2012 now have rail content included in course materials, and 9 schools offer specific rail courses.

Testimonials

"It was an excellent program. My goal was to add content to my Transportation Engineering course. REES provided an incredible amount of information in a short time."

"This was an excellent symposium for me. It was sharply focused on the topics and made clear not only what is available for educators, but also how much of a need there is for new engineers."

Acknowledgements:

- *AREMA staff and leadership*
- *AREMA Committee 24 – education & training*
- *Academic subcommittee members & speakers*
- *Industry sponsors & speakers*
- *NURail and US DOT RITA*

Educational News from Rose-Hulman Institute of Technology

Professor James McKinney

The Rose-Hulman Civil Engineering program offers a rigorous hands-on education with in-depth senior project work, allowing students to leave Rose-Hulman exceptionally well-prepared and in-demand. The program is sound in the fundamental principles of science and engineering, providing a solid base for life-long professional learning. It is designed to prepare the student for a productive career in industry as well as advanced graduate study.

Railroad Classes

Rose-Hulman Institute of Technology has offered rail related classes for the past 5 years. As a result of attending REES 2008 three weeks (12 class periods) of rail instruction were added to Introduction to Transportation Engineering, a class that had exclusively concentrated on highway engineering.

Following REES 2010 and REES 2012 a new NURail sponsor course - Railroad Engineering - was first offered during the Spring Quarter 2013. The class that was developed was a quarter long (40 class meetings) introductory, interdisciplinary, undergraduate Railroad Engineering course suitable as technical elective for Civil, Mechanical, and Electrical Engineering undergraduate students. The course was designed to include civil, mechanical, and electrical engineering topics relevant to railroad engineering. Course modules included: introduction to the railroad industry; railroad infrastructure; rail systems; curves and gradients; track systems; switches and turnouts; maintenance of way; railroad power; locomotives and rolling stock; signaling; grade crossings; operational safety systems; passenger rail, and future rail opportunities. In addition students were exposed to the rail industry through guest speakers; attendance at professional railroad meetings; site visits; student professional society meetings; local historical rail groups and museums. Railroad Engineering has been taught for the past three years, with yearly evaluation and upgrading of the course. Course content has been reviewed by faculty from Civil, Mechanical and Electrical Engineering.

Railroad Projects

Three rail related projects were taken on as part of the year long Senior Design Capstone class. Two rail projects were also part of the Freshman Design class. During the spring of 2014 students in the Railroad Engineering class designed and constructed a 60 foot section of track at the Wabash Valley Railroaders Museum. The track is used to display a WW II Pullman Troop Sleeper car.

AREMA Student Chapter

A valuable addition to the rail related curriculum was the formation of an AREMA Student Chapter. The RHIT AREMA chapter was founded in 2012 as the 12th national chapter. Since its inception the RHIT AREMA Student Chapter has scheduled 19 technical meetings and 13 site visits to Class I and regional railroad operations. Students also attended the 2012, 2013, and 2014 AREMA National Meetings. A number of students have received scholarship from AREMA as well as railroads. A number of students have participated in rail summer internships. Two members of the Class of 2014 accepted permanent employment with BNSF. AREMA is a valuable asset for our rail program.

Rail Highway Grade Crossing Roughness Quantitative Measurement Using 3D Technology

Teng Wang[1], Reginald R. Souleyrette[1], Daniel Lau[2], and Peng Xu[3]
[1] Department of Civil Engineering, University of Kentucky, Lexington, KY
[2] Department of Electrical and Computer Engineering, University of Kentucky, Lexington, KY
[3] School of Transportation, Beijing Jiaotong University, Beijing, China

Quality of surface is an important aspect affecting both the safety and the performance of at-grade rail-highway crossings. No quantitative method currently exists to quickly and economically assess the condition of rail crossings in order to evaluate the long-term performance of crossings and set a quantitative trigger for their rehabilitation. The conventional method to measure the surface quality of crossings is based on expert judgment, whereby crossing surfaces are classified as poor, fair, or good after an inspector visits and drives over the crossing. However, actual condition of the crossing could be different from the subjective rating. Poor condition rating crossings may not always present the most cost-effective locations for preventive maintenance to lower overall life-cycle costs. A quantifiable and extensible procedure is desired. With rapid advances in computer science, 3D sensing and imaging technologies, it seems logical that a cost-effective quantitative method could be developed to determine the need to rehabilitate rail crossings and assess long-term performance. Fundamental to the quantification of crossing condition is the acquisition of an accurate 3D surface model of the crossing in its present state. This research reports on the development of an accurate, low cost and readily deployable sensor capable of rapid collection of this 3D surface. The research is seen as a first step towards automating the crossing inspection process, ultimately leading to the quantification and estimation of future performance of rail crossing.

Introduction

While track roughness may be evaluated by the railroad geometry car, highway crossings are usually qualitatively evaluated. Previous work by the University of Kentucky [1] investigated a laser-based inertial profiler and rolling dipstick for applicability in evaluating rail crossing roughness. Results were of limited practicality. In that research, investigation of alternative technology was recommended

Due to the heterogeneous nature of a highway rail crossing (longitudinal and lateral slopes), it is difficult or impossible to field rate a crossing (by driving over it) and establish its performance for many combinations of crossing vehicle types, speeds, and lateral placement. To model its performance, an accurate 3D terrain model is required. The goal of the research is to develop and test a low-cost sensor based on 3D structured light technology for measuring rail crossing surfaces and to develop a method for evaluating crossings to support both safety and maintenance programs. The data and information shown here are based on the conference paper presented at the 2014 Joint Rail Conference [2] by the research team.

Design and Build Data Acquisition System (DAS)

We have designed, built, and tested a 3D structured light-based data acquisition system (DAS) that creates an accurate surface point cloud of a crossing. The scanner has a minimum scan area of 3’ x 5.1’ when the projector’s lens is 42” above ground and a maximum scan area of 6’ x 10.2’ when the projector’s lens is 80” above the ground. The DAS camera has 1280 x 800 pixel resolution. Therefore, pixels are about 0.25 centimeters average in size when the lens is at its highest point above the ground. It is possible to scan at a rate of about one scan per 30 seconds in the field.

As a scanner platform, a rail cart was built to include a frame with wheels, a laptop computer with structured light data capturing software, an 1100 watt AC/DC converter, power cables, and power provided by the battery of a test vehicle as shown in Figure 1.

Figure 1. DAS prototype.

A series of lab tests have been performed to test the camera, lens, projector, and software. During these tests, the DAS prototype was incrementally improved. For example, lenses were changed to the wide angle variety in order to capture larger scanning areas. The center supporting beam has been replaced by a taller one (also to provide a larger scanning area). Scanning software was also updated after debugging.

Field Tests

Several field tests have been conducted at crossings around Lexington, KY and at the site of the Bluegrass Railroad Museum in Versailles, KY. Figure 2 pictured one field test at the crossing (USDOT 719862A) on Beasley Rd., Versailles, KY. There was one scanner mounted at each end of the beam of the DAS. Each scanner took one scan of one side of the crossing alternatively to avoid light pattern crossing each other. In the end, there were a total of 52 scans collected for this crossing. The test took about two hours. During the scanning process, each scan was 6’ x 10.2’ in size and had a one foot overlapped area in the longitudinal direction with the other scans before and after it. Two scanned 3D point clouds were shown in Figure 3.

Figure 2. Field Test at the crossing (USDOT 719862A) on Beasley Rd. Versailles, KY.

Figure 3. Sample of data collected in the field.

Data Analysis

Each 3D point cloud “tile” is measured as 10’ x 6’ in area with 1280 x 800 resolutions at the size of about 30 megabytes. Two adjacent scans can be stitched and merged by using data comparison (using our scanning software) within the overlapped area. For example, in the field test, there were a total of 52 scanned 3D point clouds collected for that crossing. By using the overlapped area of every two contiguous scans, all scans were stitched and merged into one whole crossing surface 3D cloud as shown in Figure 4.

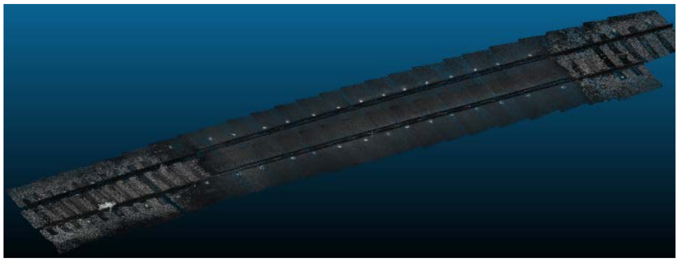


Figure 4. A highway rail crossing surface 3D point cloud.

After all the 3D point cloud tiles were merged into one crossing surface, each point had X, Y, Z coordinates recorded (to the nearest millimeter). A color-coded rendering of the crossing surface elevations can be seen in Figure 5. Blue indicates lower elevation, while red shows the higher elevations. With the 3D point cloud, the distance between any two points of the crossing can be measured. Locations where a vehicle (truck, trailer, etc.) may get high-centered or hung-up on the crossing may be directly computed given vehicle dimensions of wheel base and clearance height.

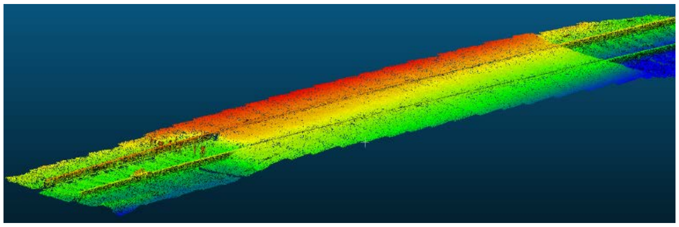


Figure 5. Elevation distribution of the crossing.

Using the 3D point cloud, crossing roughness may be quantified as depth and area of cracks, area and volume of bumps or potholes, or other formulations. An example displaying surface curvature gradient is illustrated in Figure 6. Blue areas are relatively flat as compared to red areas in this visualization.

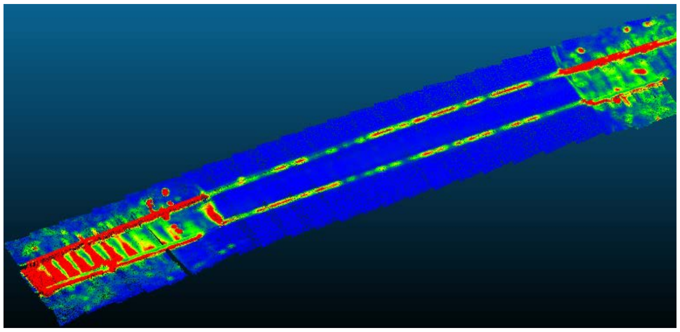


Figure 6. Surface condition (roughness) of the crossing.

Summary and Future Research

This research is only the first step in a larger effort to develop a quantitative method to assess the condition and performance of highway rail grade crossings. Further steps include:

1) Development of a roughness index based on crossing geometry.
2) Development and validation of a highway vehicle dynamics model that uses the 3D point cloud and vehicle characteristics to facilitate modeling of vehicular accelerations at various speeds and lateral positioning.
3) Development of a crossing condition index based on vehicular accelerations for a design vehicle(s).

Reference

[1]. Rose, J G., T. Witt., A. Renfro and N. Ridgeway, Research Report KTC-09-07/FR136-04-4F. “Highway-Railway At-grade Crossing Structures: Rideability Measurement and Assessments,” Available from: http://www.ktc.uky.edu/files/2012/06/KTC_09_07_FR_136_04_4F.pdf.

[2]. Wang, T., R. Souleyrette, D. Lau and P. Xu, “Rail Highway Grade Crossing Roughness Quantitative Measurement Using 3D Technology,” Proceedings of the 2014 Joint Rail Conference, Colorado Springs, CO, April 2-4, 2014.

The authors would like to thank the National University Rail (NURail) Center, a US DOT-OST Tier 1 University Transportation Center for sponsoring this study. We would like to thank the following individuals for their contributions: Sam Carter of CSX Transportation and Professor Jerry Rose from the University of Kentucky.

Quantifying Rail-Highway Grade Crossing Roughness: Accelerations and Dynamic Modeling

Teng Wang[1], Reginald R. Souleyrette[1], Daniel Lau[2], Ahmed Aboubakr[3] and Edward Randerson[3]
[1] Department of Civil Engineering, University of Kentucky, Lexington, KY
[2] Department of Electrical and Computer Engineering, University of Kentucky, Lexington, KY
[3] Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, Chicago, IL

Quality of surface is an important aspect affecting both the safety and the performance of rail-highway grade crossings. Roughness may increase the risk of crashes for both trains and automobiles. With many crossings, maintenance management is a large undertaking. As with other highway assets, crossings deteriorate if not maintained, and life cycle cost increases without preventive maintenance. No quantitative method currently exists to assess the condition of rail crossings in order to evaluate the performance of crossings and set a quantitative trigger for their rehabilitation. Since conventional inspection relies on qualitative judgment based on driving a vehicle over the crossing, it cannot assess ride experienced by different vehicles nor can it differentiate between the effects of as-built geometry and crossing deterioration. A quantifiable and extensible procedure is desired. This research reports on the use of LiDAR to collect a 3D surface point cloud as input to a customized vehicle dynamic model. The model predicts accelerations experienced by highway vehicles using the crossing. Actual accelerations at the crossing are compared to the model estimates as a first step towards developing a simple, repeatable method for quantifying crossing roughness for policy and maintenance input.

Introduction

The objective of the research is to develop a method to quickly and inexpensively quantify the roughness of a crossing, and based on correlations between roughness and safety, help prioritize crossings for rehabilitation. As a first step, a low-cost 3D data acquisition system (DAS) based on 3D structured light imaging technology has been developed as reported in a paper given at the Joint Rail Conference [1]. As an extension of the research, a vehicle dynamic model that uses a 3D surface point cloud and vehicle wheel paths to estimate highway vehicle acceleration has been developed by the authors [2]. By combining measurement and simulation technologies, this research represents a next step towards development of a methodology to quantify crossing roughness condition as a function of acceleration caused by crossing surface variation. This report focuses on the collection and analysis of acceleration data and the use of a vehicle dynamic simulation model to quantify rail-highway grade crossing roughness. The methods presented in this research are tested for repeatability and data accuracy.

Test Location and 3D Surface Point Cloud

A field test was conducted at the Norfolk Southern Brannon Road Crossing in Jessamine County, KY, just south of Lexington (USDOT 841647U). Current highway traffic on Brannon Road is 5,900 vehicles per day and about 70 trains per day pass the crossing (as shown in Figure 1). The FRA Web Accident Prediction System (WBAPS) predicted number of crashes per year at this crossing is 0.042. Highway traffic at the crossing is expected to increase to 14,000 vehicles per day by 2040.

Acceleration Field Data Collection

The test vehicle chosen was a 2011 Chevrolet Impala sedan. Other equipment and devices used in field tests included 1) a real-time acceleration sensor which records and stores 3 axis (XYZ) acceleration data at 100 hertz with the range of +/- 10 g, accuracy +/- 1% and resolution at 0.010 g, 2) a laptop PC preloaded with real-time recording software, 3) a smart phone with built-in Assisted GPS (A-GPS) that records and stores the GPS coordinates and vehicle speed at 1 hertz and 4) a stop watch. Both the acceleration sensor and smart phone were mounted on the center of the dashboard of the vehicle during the test.

Figure 1. Brannon road crossing.

The driver tried to drive as close to 35 mph as possible – the speed limit of the main road in the vicinity of the crossing on Brannon Rd. Several runs were made at this speed. Other tests were run at speeds as low as 15 mph and as high as 45 mph. Note that while the advisory speed of the crossing is 15 mph, accelerations at that speed were negligible.

Only the acceleration on the Z axis (vertical direction) was used for the analysis as it is a better indicator of the roughness of the crossing. Results are plotted as Z Acceleration vs Time for a period approximately 0.5 second before to 0.5 second after the vehicle passed the crossing surface. The average speed of the vehicle passing the crossing was obtained from the smart phone GPS associated with each test (using a time stamp). The results are shown in Figures 2 and 3.

Figure 2 shows that when the test speed is held constant (35 mph), both the frequency and amplitude of acceleration from repeated tests are very close. This indicates that the test is highly repeatable and method is reliable for future work.

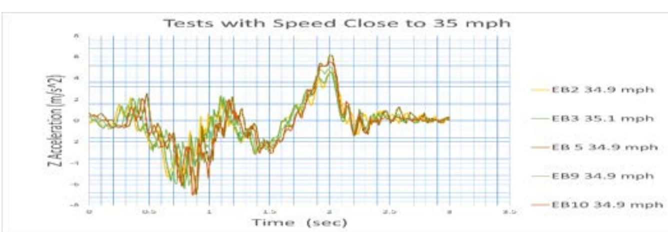


Figure 2. Tests with speed close to 35 mph.

To test the effect of speed variation on accelerations, several tests were performed at various speeds. Results of these tests are shown in Figure 3. It can be seen that, as expected, acceleration amplitudes and frequencies increase with increasing speeds.

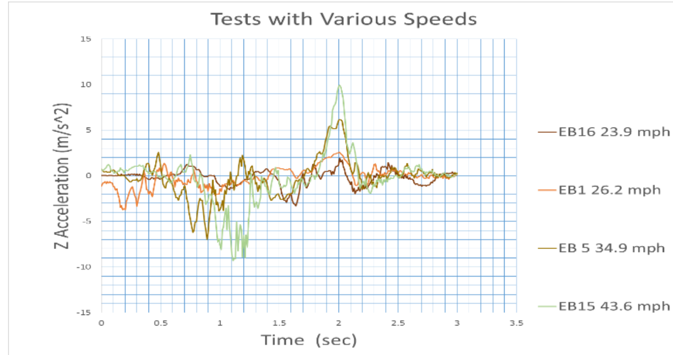


Figure 3. Tests with various speeds.

Vehicle Dynamic Model Simulation

In order to simulate the highway vehicle driving over a crossing and estimate accelerations, a highway vehicle dynamic model was developed based on the computer code ATTIF (Analysis of Train/Track Interaction Forces). The model was developed at the Dynamic Simulation Laboratory (DSL) of the University of Illinois at Chicago (UIC). Its original purpose was to simulate train and track interaction. ATTIF included a detailed wheel/rail contact model based on surface geometry (see Figure 4).

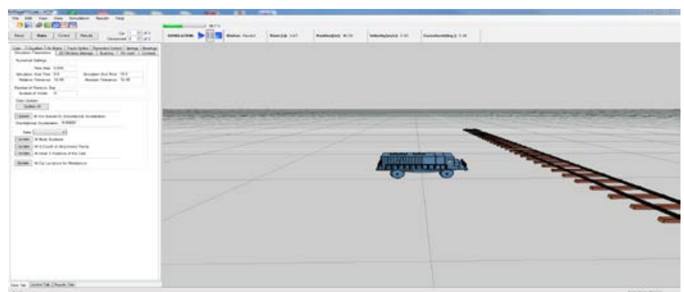


Figure 4. ATTIF-based vehicle dynamic simulation model.

The authors modified the ATTIF vehicle dynamic model which uses the 3D surface point cloud coordinate data together with realistic vehicle parameters for weight, velocity, wheel radius, wheel base and suspension characteristics to simulate a vehicle driving over the rail crossing. During the validation and calibration process, the initial simulation acceleration result was about three times larger than the field observation. It also had a lot of high frequency noise in the wave as shown in Figure 5.

The amplitude and frequency differences between the simulation and field observation were caused by the stiffness and damping of the vehicle tires which were significantly different to rail steel wheels. After reducing the tire stiffness and increasing its damping, the model was calibrated. Simulated accelerations were then compared to field observations as discussed in the following section.

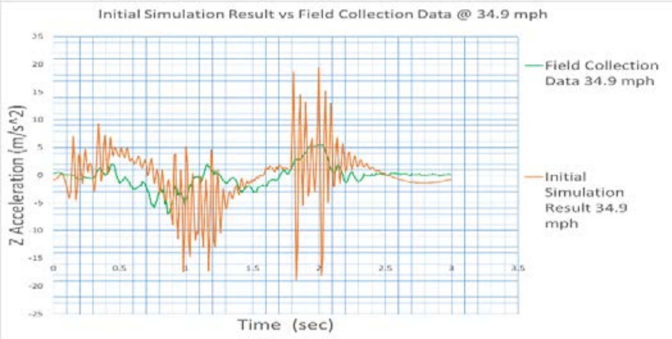


Figure 5. Initial simulation vs field data @ 34.9 mph.

Simulation Result vs Field Data

Simulation results vs. field collection data for two different speeds are shown in Figures 6 and 7.

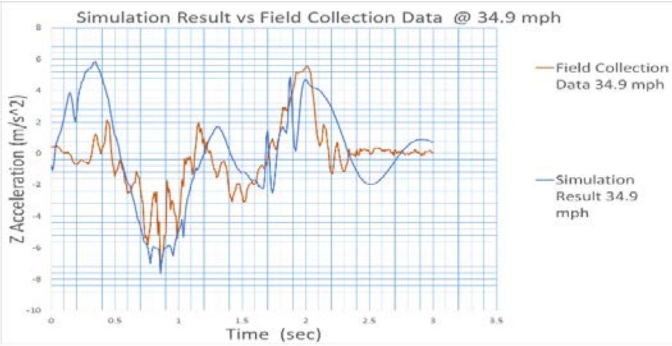


Figure 6. Simulation result vs field data @ 34.9 mph.

As can be seen in Figures 6 and 7, simulation results are similar to field observations. General trends of the acceleration waves are similar, and maximum and minimum values of accelerations are quite close. In Figure 6 (comparison at 34.9 mph), the first 0.5 second and last 0.5 second data have higher “error” but are in fact artifacts of the virtual transition of simulated profile to the assumed approaches. These regions should be ignored. To quantify the goodness-of-fit and similarity of the two waves in the plot, a MATLAB script was developed by using a cross correlation index (P in equation 1) and mean squared error (MSE). Results are shown in Table 1.

$$\text{cross correlation index } P(A{:}B) = \frac{\text{cross correlation (A:B)}}{\text{cross correlation (A:A)}}$$

where A, B are time series waves with the same number of data. And P (A:B) = 1, when wave A and B are the same shape.

TABLE 1. Simulation Results Compared to Field Collection Data

Speed	P(A:B) A=field B=simulated	MSE (normalized to maximum acceleration)	MAX(A):MAX(B) in m/s^2	MIN(A):MIN(B) in m/s^2
23.9 mph	0.4443	0.3352	1.96:4.27	-3.29:-3.51
26.2 mph	0.6522	0.1957	2.58:4.72	-3.74:-3.68
34.9 mph	0.9338	0.1553	5.56:5.84	-7.00:-7.64
43.6 mph	0.9346	0.1587	9.92:8.36	-9.32:-12.51

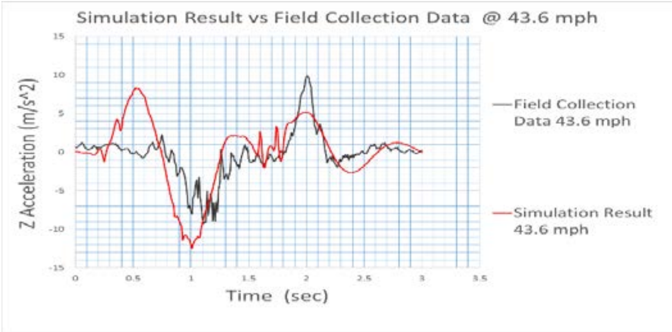


Figure 7. Simulation vs field collection data @ 43.6 mph.

Summary and Conclusion

To model rail-highway crossing roughness, a 3D surface is needed. Previously, a low cost 3D data acquisition system was developed. In this research, a vehicle dynamic simulation model was developed and calibrated using 3D data and field accelerometer readings. Test repeatability and data accuracy was verified. The vehicle dynamic model can be used to facilitate estimation of vehicular accelerations at various speeds for different vehicles and lateral positioning. In future research, a method will be developed to extrapolate acceleration readings to those experienced by any design vehicle.

References

[1]. Wang, T., R. Souleyrette, D. Lau and P. Xu, “Rail Highway Grade Crossing Roughness Quantitative Measurement Using 3D Technology,” Proceedings of the 2014 Joint Rail Conference, Colorado Springs, CO, April 2-4, 2014.

[2]. Wang, T., R.R. Souleyrette, D. Lau, A. Aboubakr and E. Randerson. “Quantifying Rail-Highway Grade Crossing Roughness: Accelerations and Dynamic Modeling.” Proceedings of the 94th Annual Meeting of TRB, Washington, DC, Jan. 2015. 11 pages

The authors would like to thank the National University Rail (NURail) Center, a US DOT-OST Tier 1 University Transportation Center for sponsoring this study.

"Grow Our Own" Minority STEM Initiative: Partnering in Outreach

C. Tyler Dick P.E. & Dr. Christopher P.L. Barkan, University of Illinois at Urbana-Champaign

The railroad programs at the University of Illinois at Urbana-Champaign (UIUC) and Michigan Technological University (MTU) are supporting efforts led by Hanson Professional Services to expose underrepresented groups to railway engineering and "grow our own" next generation of civil engineering leaders.

From Community Impact Comes Opportunity

To support higher-speed passenger rail operations between Chicago and St. Louis, a long-term effort to consolidate multiple rail corridors through Springfield, Illinois is underway. Future construction of a rail link along 10th Street will allow for a single grade-separated rail corridor to replace multiple routes through the central business district, eliminating multiple roadway grade crossings. However, the approved alternative passes within blocks of a high school and impacts minority populations in the surrounding community.

Through a unique partnership, local community leaders saw the proposed rail corridor as an opportunity to introduce local youth and minority populations to possible careers in related railway transportation, civil engineering and construction fields. The aim of the project is to help students from underrepresented groups connect the highly-visible construction, operations and maintenance activities in their community surrounding the new rail corridor to science, technology, engineering and mathematics (STEM) topics. With a tangible connection to real-world applications of these subjects, it is hoped that more of these students will pursue careers in engineering, railroads or construction industry, growing the next generation of industry professionals.

The "Grow Our Own" Minority STEM Initiative is led by Hanson Professional Services, a civil engineering consulting firm headquartered in Springfield. Hanson is joined by the City of Springfield, Sangamon County and the Illinois Department of Transportation in administering the initiative. Each group has pledged financial support to multiple programs including outreach to minorities through the NURail Center.

Program coordinators at Hanson work with nearby schools and local organizations such as the Urban League, Springfield Black Chamber of Commerce, Boys & Girls Clubs, Frontiers International and Ministerial Alliance to identify minority students in the Springfield community with an interest in STEM topics. Students are then matched with appropriate programs to foster their interest.

UIUC Engineering Open House

In March 2014, NURail and Hanson partnered to host 30 minority students from Springfield high schools and middle schools attending the Annual Engineering Open House on the UIUC campus. With bus transportation provided by Hanson, NURail graduate student Research Assistants served as tour guides to escort the Springfield students around the engineering campus. The visiting students were able to participate in hands-on activities demonstrating applications of STEM topics to various engineering fields. Among the hundreds of displays was the award-winning "Railway Extravaganza!" exhibit, consisting of a locomotive simulator and other interactive railway engineering activities, organized by the UIUC American Railway Engineering and Maintenance-of-Way Association (AREMA) Student Chapter and NURail-supported students.

While the AREMA exhibit provided a direct link to the railway project in Springfield, other exhibits on robotics, unmanned aerial vehicles, polymers and biotechnology were also popular with the Springfield students.

After the first visit proved successful, another group of 25 students from Springfield was hosted in 2015 with plans to make it an annual activity.

MTU Summer Youth Program

Thanks to travel support from Hanson and scholarships from NURail, two minority students from Springfield were able to experience a more intensive introduction to transportation and engineering concepts at the 2014 Summer Youth Program (SYP) in Rail and Intermodal Transportation hosted by Michigan Technological University. Over five days, students learn about transportation infrastructure and operations through hands-on activities and industry field trips. The popular MTU program also allows students to meet peers with similar interests but from differing backgrounds all across the United States.

Hanson and NURail plan to sponsor participation of more Springfield minority students in 2015 and at future editions of the MTU summer program.

The authors acknowledge Satch Pecori and Kevin Seals at Hanson Professional Services for their support of NURail involvement in the "Grow Our Own" initiative, and Pasi Lautala and David Nelson at MTU for coordinating minority student participation in the SYP.

New Semester Course in Railway Terminal Design & Operations

C. Tyler Dick P.E., University of Illinois at Urbana-Champaign

The new Railway Terminal Design & Operations course (CEE 598 RTD) at the University of Illinois at Urbana-Champaign (UIUC) introduces students to the role of terminals in the freight railway transportation system, the functions required at different types of terminals, and best practices for design of terminal infrastructure to support these roles and functions.

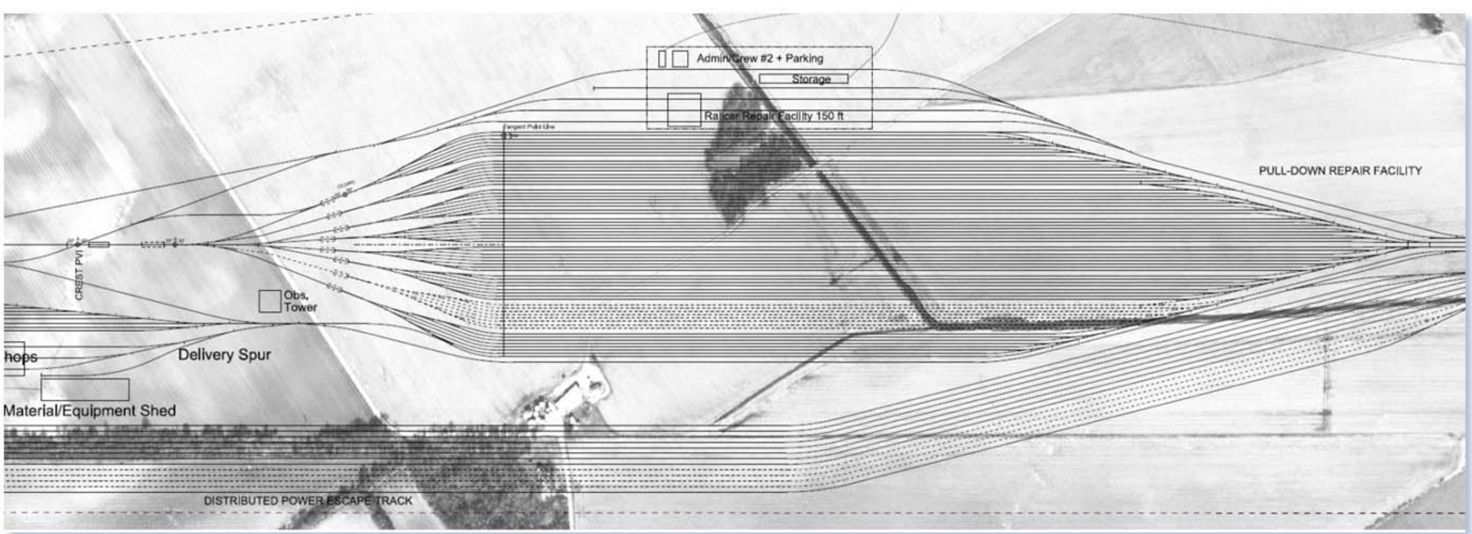
Course Rationale

The primary focus of railway engineering courses at UIUC is on infrastructure, geometry and economic justification of mainline projects to benefit passenger and line-haul freight rail operations. However, the typical railcar spends the majority of its time off the mainline, either in intermediate classification yards or specialized terminal facilities where freight is transloaded to and from rail customers or connecting modes of transportation. These facilities represent significant capital investments for the railways and, given the amount of time that railcars and trains spend in them, poor design of terminal facilities can lead to inefficiencies that quickly degrade the provided level of freight transportation service.

In the new Railway Terminal Design & Operations course (CEE 598 RTD) developed as a NURail education project, students learn details of the design, operations planning, management and optimization of the terminal facilities required for the railway network to function as an efficient freight transportation system. The focus is on design of classification yards, intermodal facilities and bulk terminals, and how these facilities are organized into a network to provide different types of freight transportation service by rail.

Lecture Topics

The lecture material developed for the course centers around three major topic areas. The first of these areas is the railway as a freight transportation system. Lectures in this portion of the course cover network operations, terminal functions, the train origination process, train planning, connections and transit time, and classification and blocking. These topics provide students with an understanding of how railcars are moved across the freight railway network and the terminal activities that are required to support these movements. This knowledge is essential for students to understand the fundamental terminal engineering and design considerations introduced in subsequent



sections of the course. As part of this background, students are also introduced to railway operations concepts such as empty railcar distribution and locomotive and crew assignment.

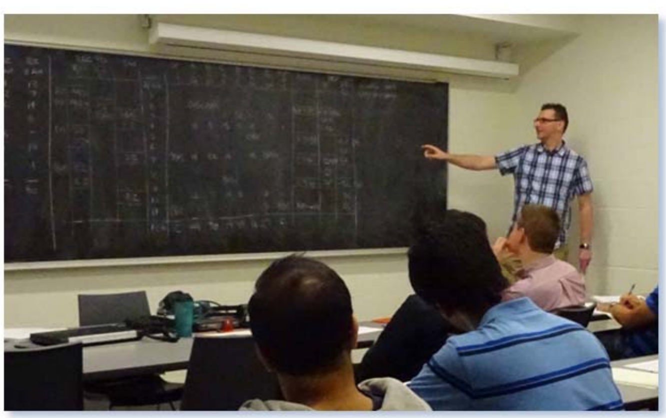
The second topic area focuses on the design of classification yards. Lectures introduce basic yard geometry, ladder tracks, flat yards and hump yards. Several lectures are dedicated to the physics and detailed design of the hump crest and retarder speed control system, a topic that several students likened to "the railroad version of fluid mechanics".

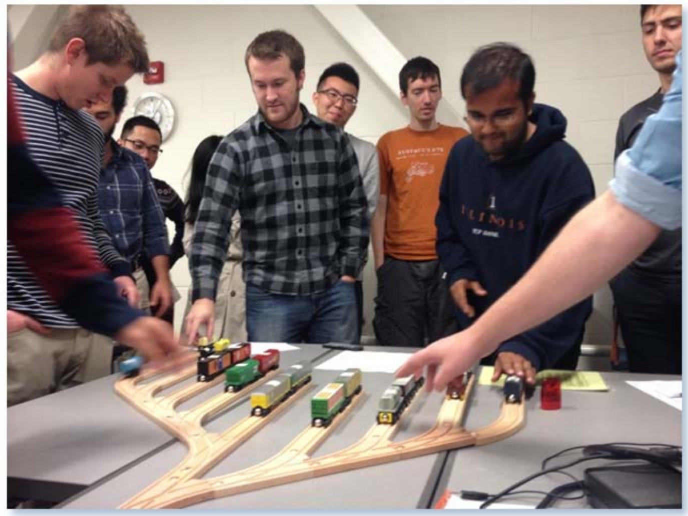
The third topic area examines specialized terminal facilities, including intermodal facilities and bulk freight terminals. In addition to facility layout, lectures cover intermodal lift equipment and bulk loading and unloading mechanisms.

Class sessions are designed to be interactive with blackboard lecturing supplemented by video clips and hands-on activities at the front of class. As an example, students are taught classification, blocking and sorting schemes by constructing a yard with wooden railway track and sorting railcars as a team.

Assignments & Design Studio

The course includes ten individual assignments to help students understand the application of course concepts. These tasks are supplemented by two larger "design studio" assignments completed with MicroStation CAD software. The MicroStation assignments allow students to develop their understanding of track geometry and how various turnouts, curves and tangents are arranged into a yard design that will operate efficiently. The two design studio assignments, a 12-track classification yard and a unit train loop unloading facility, are based on real-world projects and design criteria.





Semester Class Design Project

During the course of the semester, the CEE 598 RTD students work as a class to complete a major terminal planning study. The main components of the planning study include a track layout, control system design and operating plan for each of several project alternatives.

Through the class project, students are exposed to the matrix style of project team organization employed by design consultants. Each student is assigned a specific component of the study for a certain alternative. Successful completion of the project requires the student to collaborate with both their peers working on the same alternative and those working on the same task for the other alternatives.

The class design project also involves a design charrette and two project review meetings where the instructor functions as the project owner and students assume the role of consultants presenting their designs for review.

Inaugural Course Offering

CEE 598 RTD was offered for the first time in Fall 2014 with 23 students enrolled on the UIUC campus. The initial design project, developed in conjunction with CSX Transportation, investigated four alternative layouts for a new hump classification yard near Terre Haute, IN and a new intermodal facility near Indianapolis, IN. The student design submittals exceeded expectations. Overall the course was ranked as "excellent" by the students enrolled, marking it as another NURail success.

The author acknowledges the support of Jeremiah Dirnberger, Manager – Network Modeling & Analytics CSX Transportation, in development of the course.

Study of Liquid Sloshing using a Multibody Approach

Liang Wang[1], Jesús R. Jiménez Octavio[2], Cheng Wei[3], and Ahmed A. Shabana[1]

[1]Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, 842 West Taylor Street, Chicago, IL 60607.
[2]Mechanical Engineering Department, Comillas Pontifical University, Madrid, 25-28015, Spain
[3]Department of Astronautics Engineering, Harbin Institute and Technology, Harbin, Heilongjiang, 150001, China

The objective of this investigation is to develop a total Lagrangian liquid sloshing solution procedure based on finite element floating frame reference (FFR) formulation and absolutely nodal coordinate formulation (ANCF). The proposed liquid sloshing modeling approach can be used to avoid the difficulties of integrating most of fluid dynamics formulations, which are based on the Eulerian approach, with multibody system dynamics formulations. The use of this approach allows for developing an inertia-variant fluid model that accounts for the dynamic coupling between different modes of the fluid displacements. The FFR model is integrated with a MBS railroad vehicle model in which the rail/wheel interaction is formulated using a three-dimensional elastic contact formulation that allows for the wheel/rail separation. Several simulation scenarios are used to examine the effect of the distributed liquid inertia on the motion of the railroad vehicle. The results, obtained using the sloshing model, are compared with the results obtained using a rigid body vehicle model. The comparative numerical study presented in this investigation shows that the effect of the sloshing tends to increase the possibility of wheel/rail separation as the forward velocity increases, thereby increasing the possibility of derailments at these relatively high speeds. Several ANCF examples are also presented in this investigation in order to shed light on the potential of using the ANCF liquid sloshing formulation used in the railroad field.

Numerical Results

Sloshing effect on the motion of railroad vehicle. In order to examine the sloshing effect on the motion of the vehicle, another equivalent rigid-body model was used for the purpose of comparison. This rigid body model is obtained by assuming the fluid body to be rigid while keeping all other model parameters the same. Both tangent and curved track are used in this investigation to examine the sloshing effects.

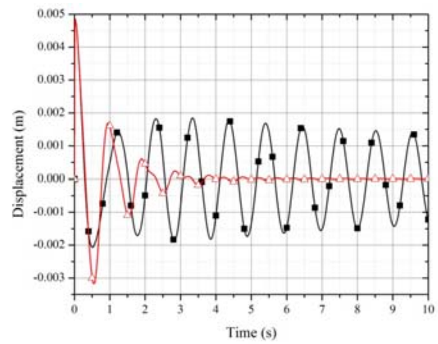


Fig. 1 Lateral displacement of the rear wheelset with forward velocity of 25m/s (56mph) (—■—Rigid body , —△— Flexible body)

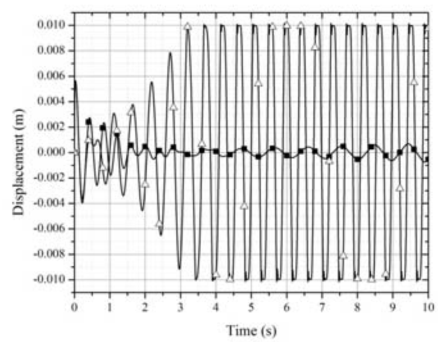


Fig. 2 Lateral displacement of the rear wheelset with forward velocity of 60m/s (134mph) (—■—Rigid body , —△— Flexible body)

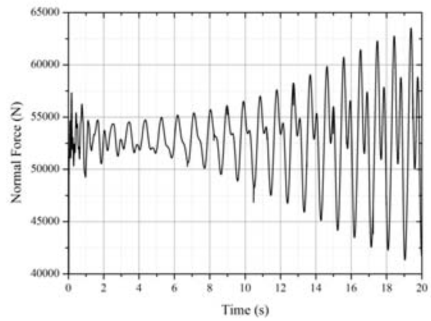


Fig. 3 Normal contact force on the right wheel of the rear wheelset of the rear bogie in the rigid body model with forward velocity of 60 m/s (134mph)

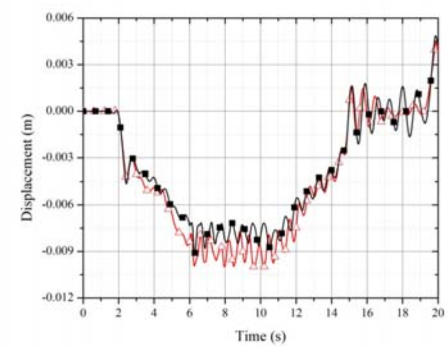


Fig. 4 Lateral displacement of the rear wheelset with respect to the track (—■—Rigid body, —△— Fluid body)

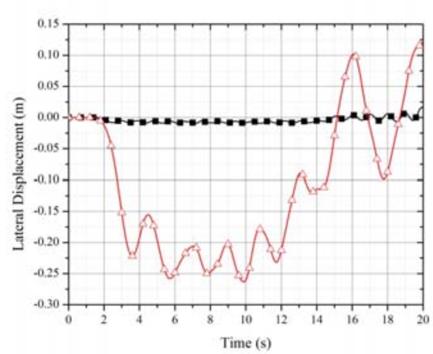


Fig. 5 Change of the center of mass with respect to the track (—■—Rigid body , —△— Fluid body)

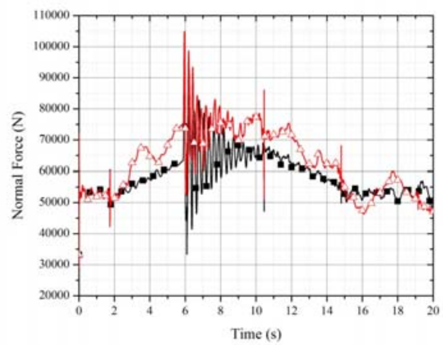


Fig. 6 Normal contact force of the right wheel of the rear wheelset of the rear bogie (—■—Rigid body , —△— Fluid body)

In the first simulation scenario considered, two constant forward velocities of 25 m/s (56 mph) and 60 m/s (134 mph) along the tangent track are considered. All wheelsets are assumed to have 0.5 m/s initial lateral velocity. Figure 1 shows that, at the low speed when hunting is not significant, the fluid body introduces damping that tends to reduce the amplitude of the hunting oscillations, making the system more stable as compared to the rigid body model. However, if the forward velocity is increased to 60 m/s (134 mph), the fluid body model becomes more unstable as compared to the rigid body model, as demonstrated by the results of Fig. 2. Figures 3 shows the normal force for the rigid and fluid body models, respectively. The results presented in these two figures show that the liquid sloshing can cause impulsive forces between the wheel and rail, leading to spikes in the contact force. More importantly, the liquid sloshing can lead to wheel/rail separations which can increase the possibility of rollover and derailment.

In the second simulation scenario, the results obtained using the rigid and fluid body models are compared when the vehicle negotiates a curved track at 35 m/s speed with no initial lateral velocity. Figure 4, which depicts the lateral displacement of the wheelset with respect to the track, shows that the fluid body model has larger lateral displacement due to the sloshing effect. Figure 5 shows the change in the location of the center of gravity of the fluid body in the lateral Y direction. The results of this figure show that the change in the position of the center of mass is more significant when the vehicle negotiates a curved track. The results of Figs. 6 shows that changing the location of the fluid body center of mass leads to a different distribution of the normal contact forces on the wheels. That is, the wheels which carry the highest loads in the fluid body and the rigid body models can be different.

ANCF fluid element capability. The dimensions of the element are $a = b = c = 1\text{m}$, while the mass density $\rho = 1.0\times10^3\ \text{kg/m}^3$, the gravity force $\mathbf{F}_g = [0\ \ 0\ \ \text{-}9.8]^{\text{T}}\ \text{m/s}^2$, the penalty coefficient $k_{IC} = 1.0\times10^6\ \text{N/m}$, and the shear viscosity $\mu = 0.00093\,\text{Pa}\cdot\text{s}$. The simulation time is assumed to be 1s. In this simulation scenario, the fluid element bottom surface is assumed to be in contact with the ground. The fluid is assumed to move freely under the effect of gravity. The results obtained also demonstrated that the fluid maintained constant volume. This simulation scenario also shows that the proposed ANCF fluid elements can capture large displacements using a total Lagrangian approach, as shown in Fig. 7.

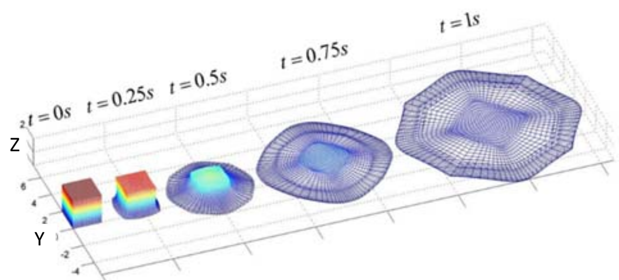


Fig. 7 Eight-element fluid/ground surface interaction

In other example, the one-element model previously considered in this section is used to fill a container subjected to a prescribed harmonic motion with different frequencies in the *y* direction. As shown in Fig. 8, when the container movement is $0.1\sin(3t)$, the fluid experiences sloshing and the height reaches 1.16 m. The height reaches 1.35m for the $0.1\sin(8t)$ movement and 2.23m for the $0.3\sin(8t)$ movement. By investigating these three results, one could see that if the harmonic motions have the same amplitude, increasing the frequency would lead to the more sever fluid sloshing while in the other case, if the harmonic motions have the same frequency, increasing the amplitude would also lead to more sever fluid sloshing which are consistent with common sense. More details on FFR and ANCF modeling of the rail car liquid sloshing may be found in the investigations [1, 2].

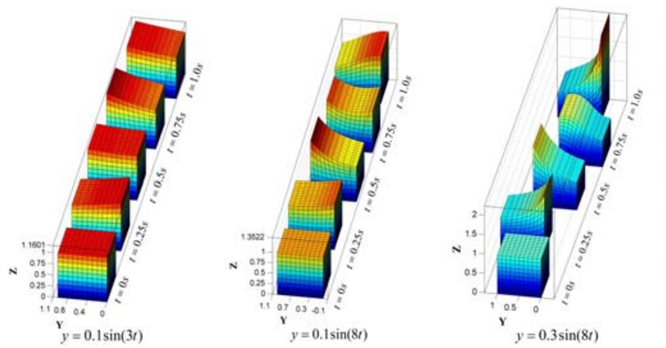


Fig. 8 Sloshing problems solution using one finite element

References

1. Wang, L., Octavio, J.R.J., Wei, C., and Shabana, A.A., 2014, "Low Order Continuum-based Liquid Sloshing Formulation for Vehicle System Dynamics", ASME Journal of *Computational and Nonlinear Dynamics*. Vol. 10(2), Article ID 021022.
2. Wei, C., Wang, L., and Shabana, A.A., 2014, "A Total Lagrangian ANCF Liquid Sloshing Approach for Multibody System Applications", ASME Journal of *Computational and Nonlinear Dynamics* (in press).

This research was supported by the National University Rail (NURail) Center, a US DOT-OST Tier 1 University Transportation Center.

Switch Geometry Modeling using ANCF

Martin B. Hamper[1], Cheng Wei[2], and Ahmed A. Shabana[1]

[1]Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, 842 W. Taylor St, Chicago, 60607, United States of America

[2]Department of Aerospace Engineering, Harbin Institute of Technology, Harbin, Heilongjiang 150001, China

In the analysis of multibody system (MBS) dynamics, contact between two arbitrary rigid bodies is a fundamental feature in a variety of models. Many procedures have been proposed to solve the rigid body contact problem, most of which belong to one of the two categories: offline and online contact search methods. This investigation will focus on the development of a contact surface model for the rigid body contact problem in the case where an online three-dimensional non-conformal contact evaluation procedure, such as the elastic contact formulation—algebraic equations (ECF-A), is used. It is shown that the contact surface must have continuity in the second-order spatial derivatives when used in conjunction with ECF-A. Many of the existing surface models rely on direct linear interpolation of profile curves, which leads to first-order spatial derivative discontinuities. This, in turn, leads to erroneous spikes in the prediction of contact forces. To this end, an absolute nodal coordinate formulation (ANCF) thin plate surface model is developed in order to ensure second-order spatial derivative continuity to satisfy the requirements of the contact formulation used. A simple example of a railroad vehicle negotiating a turnout, which includes a variable cross-section rail, is tested for the cases of the new ANCF thin plate element surface, an existing ANCF thin plate element surface with first order spatial derivative continuity, and the direct linear profile interpolation method. A comparison of the numerical results reveals the benefits of using the new ANCF surface geometry developed in this investigation.

Introduction

The objective of this work is to develop a new finite element based procedure for representing surface geometry in MBS contact problems. This procedure ensures a certain degree of continuity at the element interface, thereby allowing for more accurate predictions of kinetics results that include the contact forces. Specifically, the main contributions of this investigation can be summarized as follows:

(1) The investigation clearly identifies and explains the limitations of using curve representations in the description of surface geometry. It also identifies and explains the limitations of using low-order interpolations with contact formulations that demand a higher degree of continuity. These two geometric approaches for modeling surfaces can lead to fundamental kinematic and kinetic problems that cannot be ignored in the analysis of important engineering applications such as railroad vehicle systems.

(2) This communication proposes a new finite element-based surface geometry that ensures higher degree of continuity at the element interface. The new geometry, which is based on ANCF finite elements, is proposed in order to address the fundamental problems associated with the use of the curve representation or the use of lower-order interpolation. A biquintic interpolation is used in order to address the kinetic problems that result from the use of other existing geometric descriptions.

(3) This work presents for the first time a comparative analysis, both qualitative and quantitative, to demonstrate the value of using the proposed geometry approach. To this end, three different approaches are compared analytically and numerically. These three approaches are the curve representation for the surface, the low-order surface interpolation, and the proposed

higher-order surface interpolation. The results of this study demonstrate that the use of higher-order surface interpolation is feasible in many challenging problems.

(4) Finally, a numerical example of a rail vehicle negotiating a turnout is used to demonstrate the feasibility of using rail CAD geometry model that can be systematically integrated with complex MBS models. The example presented in this brief clearly demonstrates the need for the use of the new geometric approach to model important technological applications. The results also demonstrate clearly the limitations of other existing approaches.

This investigation has been published in an extended manner in [1].

Numerical Results

The numerical simulations are carried out for three different scenarios that correspond to the three surface types (curve representation, low-order interpolation, and high-order interpolation) discussed in this investigation. The results obtained using the three different surfaces are compared. The simulations are carried out using the online non-conformal elastic contact formulation (ECF-A) implemented in the general purpose multibody package SAMS/2000. Among the three models, the fastest is the linear interpolation method, which requires 5 min and 8 s of CPU time on a personal computer using serial computations, while the cubic ANCF method required 5 min and 27 s, and the quintic ANCF method required 6 min and 22 s. The simulations were performed using an Intel PC with i5-2400 CPU that has a clock speed of 3.10 GHz. While the linear interpolation is faster, the improved accuracy of the quintic ANCF method far overweighs the additional CPU time it requires as will be demonstrated by the numerical results. The best agreement in the results is found in the location of the contact point. In Fig. 1, it is shown that the difference in the computed lateral position of the contact point is negligible between the cubic and quintic ANCF thin plate models, while the discrepancies are more pronounced when compared to the linear profile interpolation method. Note that the large shift in the location of the contact point at 7.9502 m (313 in.) corresponds to time at which the contact point switches from the stock rail to the tongue rail. A similar phenomenon can be seen in the plot of the vertical position of the contact point shown in Fig. 2. As the contact point transitions from the stock rail to the tongue rail, there is a small vertical shift downward. Following this, the contact point shifts vertically by 6.35 10^{-3} m (0.25 in.) as per the design of the tongue rail, which includes this elevation increase. It is also important to note here the linear nature of the change in the vertical position of the contact point in the case of the direct profile interpolation method. Recall that linear interpolation is used in the longitudinal interpolation between any two profiles; consequently, this leads to a linear change in the height of the profile along the rail space curve. This phenomenon is less pronounced in the lateral shift as the individual profiles are described with cubic interpolation. Figure 3 shows the trace of the contact points along the left rail in the proximity of the tongue rail. Here, the cause for the lateral shift is more pronounced: the contact point shifts laterally to follow the stock rail until such a time that the primary contact point transitions from the stock rail to the tongue rail. The difference between the three examples is much more pronounced in the normal contact forces. In Fig. 4, a comparison is shown for the normal contact force at the left wheel/rail interface between the direct linear interpolation method and the quantic ANCF thin plate mesh. Here, it can be seen clearly that the linear interpolation method produces fictitious spikes in the forces, which is certainly an undesirable and unrealistic feature.

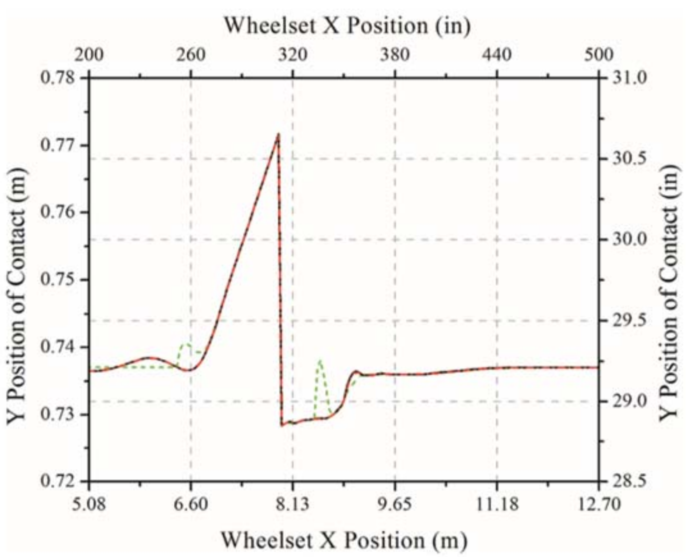


Fig. 1 Y Coordinate of contact point on left rail (green- linear interpolation; red-cubic plate; black-quintic plate)

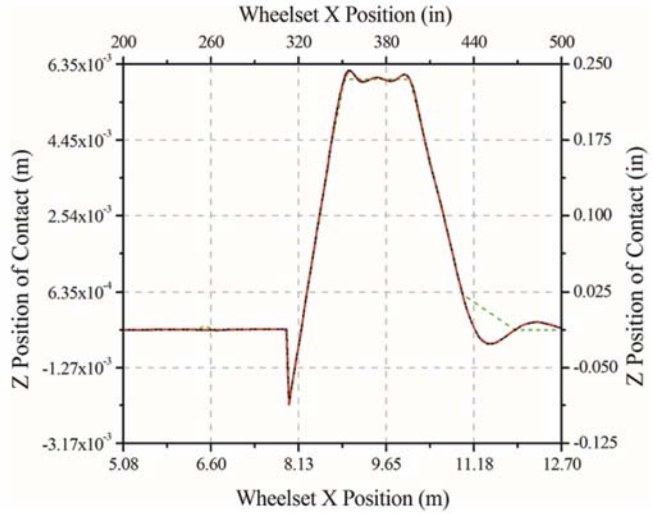


Fig. 2 Z Coordinate of contact point on left rail (green- linear interpolation; red-cubic plate; black- quintic plate)

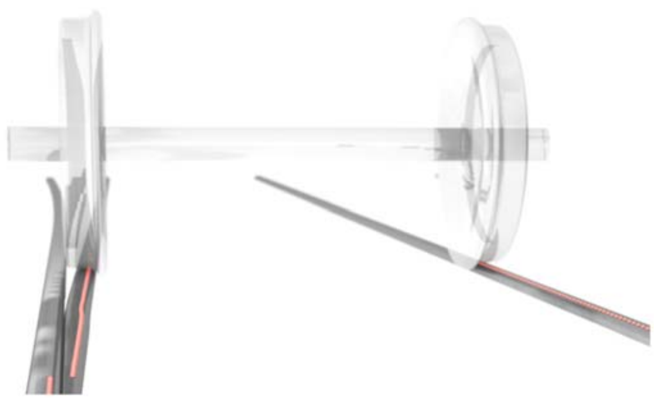


Fig. 3 Trace of contact point along quintic ANCF thin plate turnout

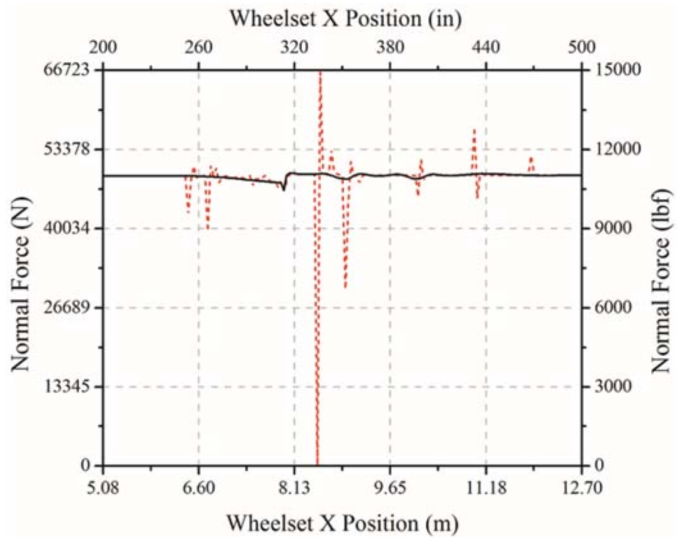


Fig. 4 Normal force at left contact linear interpolation (dashed red line) versus quintic plate (solid black line)

This research was supported by the National University Rail (NURail) Center, a US DOT-OST Tier1 University Transportation Center.

References

[1]. Hamper, M.B., Wei, C., and Shabana, A.A., 2015, “Use of ANCF Surface Geometry in the Rigid Body Contact Problems: Application to Railroad Vehicle Dynamics”, *Journal of Computational and Nonlinear Dynamics*, Vol. 10, 021008, pp. 1-12.

Nonlinear Track-Railroad Vehicle Interaction

Antonio M. Recuero[1], Javier F. Aceituno[2], José L. Escalona[2], and Ahmed A. Shabana[1]

[1]Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, 842 W. Taylor St, Chicago, 60607, United States of America
[2]Department of Mechanical and Manufacturing Engineering, University of Seville, Camino de los Descubrimientos s/n, Seville, 41092, Spain

This investigation describes a new nonlinear formulation based on the absolute nodal coordinate formulation (ANCF) for modeling the dynamic interaction between rigid wheels and flexible rails. The generalized forces and spin moments at the contact points are formulated in terms of the absolute coordinates and gradients of ANCF finite elements used to model the rail. To this end, a new procedure for formulating the generalized ANCF applied moment based on a continuum mechanics approach is introduced. In order to have an accurate definition of the creepages, the location and velocity of the contact points are updated online using the rail deformations. An elastic contact formulation that allows for wheel/rail separation is used to define the contact forces that enter into the dynamic formulation of the system equations of motion. An elastic line approach is used to define the rail stress forces, and the relative slip between the rigid wheel and the flexible rail is iteratively updated using the deformations of the ANCF finite elements. The formulation proposed in this investigation is demonstrated using a five-body railroad vehicle negotiating flexible rails. In order to validate the ANCF rail model, the obtained results are compared with previously published results obtained using the floating frame of reference (FFR) formulation that employs eigenmodes. The comparative study presented in this work shows that there is, in general, a good agreement between the results obtained using the two different formulations.

Introduction

As is well known, the wheel/rail contact interaction forces have a significant effect on the dynamics and stability of railroad vehicle systems. These forces are a function of several variables such as the dimension of the contact area, creepages, material properties, and the track flexibility. In the area of railroad vehicle dynamics, many investigations have been focused on the track flexibility, which influences the location of the contact points and the overall dynamic behavior of railroad vehicles. Consequently, it is important to consider track flexibility in order to be able to accurately predict the wheel/rail contact forces and examine the vehicle response in many simulation scenarios and loading conditions. Some reasons for the need to include the effect of track flexibility in multibody system (MBS) railroad vehicle simulations are given below.

- Including the effect of the track flexibility allows for more accurate modeling of the vehicle/track coupling.
- More accurate models for wheel and rail wear and fatigue can be developed by considering the effect of track motion and flexibility.
- The deformation of a track allows for an accurate prediction of the creepages, which are required in the formulation of the creep forces. These forces influence the dynamics and stability of railroad vehicle systems.
- Accurate studies of the effect of temperature, buckling, gage widening, loss of rail stiffness, etc. require the use of the more accurate flexible rail models.

This investigation uses the Floating Frame of Reference (FFR) formulation which allows for introducing the flexibility of linearly elastic railroad tracks, and the Absolute Nodal Coordinate Formulation (ANCF), which is a fully nonlinear method, to include the dynamics and flexibility of the tracks and the interaction with the vehicle. An extended version of this work is underway [1].

Models and Case Study

In this section, the vehicle and track models as well as various case studies discussed in the numerical results section are presented. A 5-body railroad vehicle model is simulated on three tangent track models: a rigid track, and flexible ANCF and FFR tracks. In addition, the flexible tracks are analyzed considering a scenario characterized by the lack of attachment between sleepers and rail. The case study considers the original stiffness and damping properties, but it includes the effect of the loss of contact between two consecutive sleepers and the right rail.

Vehicle Model. The vehicle model used in this investigation consists of a 5-body suspended bogie running at a constant forward velocity over a tangent track. The model includes two wheelsets, two equalizers, and a frame. Sixteen bushings and four bearings elements connect the vehicle bodies. The velocity constraint is imposed on the pitch coordinate of the rear wheelset, with a value of $\dot{\theta}_y = 37.1$ rad/s, which yields an approximate forward velocity of 17 m/s.

Track Models. Two different flexible track models are developed using the formulations described in previous sections of this brief. ANCF and FFR track models are used in this work.

Case Studies. One case study is considered to compare ANCF and FFR flexible track models. In this case, standard track lateral and vertical damping and stiffness properties are used with the assumption that two consecutive sleepers lose contact with the right rail. This case is used to analyze the loss of contact between the rail and sleepers as a consequence of a gap between the ballast and the sleepers. These structural flaws may cause severe damage.

Numerical Results

This example represents a damaged track which has standard material. However, a loss of contact between two consecutive sleepers and the right flexible rail segment is assumed.

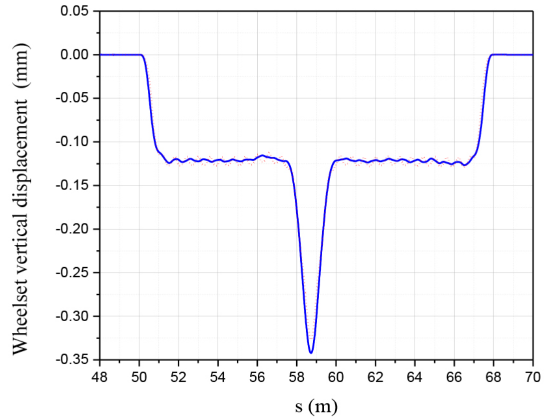


Fig. 1 Rear wheelset vertical displacement with lack of sleepers (——FFR, ············ANCF)

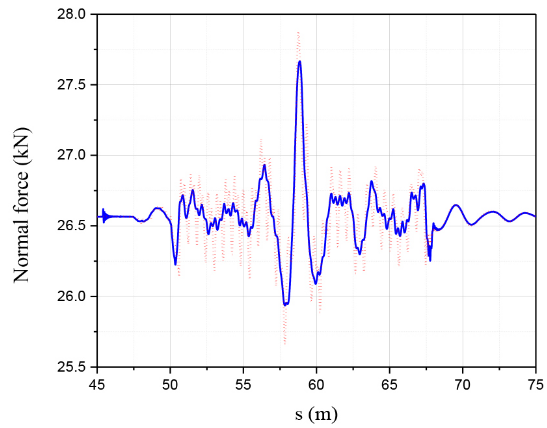


Fig. 2 Rear wheelset normal force with standard stiffness and lack of sleepers (——FFR,············ ANCF)

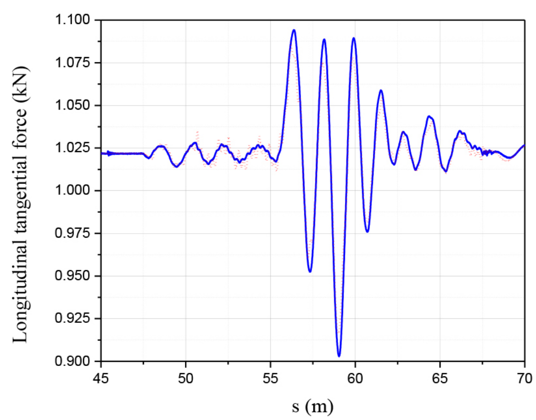


Fig. 3 Rear wheelset longitudinal force with lack of sleepers (——FFR,············ANCF)

This scenario is modeled by removing the damping and stiffness elements of two sleepers at locations $s = 58.4$ m and $s = 59$ m. Figure 1 shows the rear wheelset vertical displacement, where the peak value is caused by the lack of the sleeper stiffness. Figures 2-5 show the normal and tangential contact forces. The results of the normal contact force, shown in Fig. 2, show change of approximately 4% when there is no contact between the rail and the sleepers. On the other hand, the results of the longitudinal tangential force of Fig. 3 show oscillations of about 9%. The lack of sleepers clearly influences the value of the longitudinal creepage. The lateral tangential force and spin moment also show sudden changes as shown in Figs. 4 and 5. The results presented in these figures are consistent with the results reported in previous investigations which considered the effect of the lack of sleeper contact.

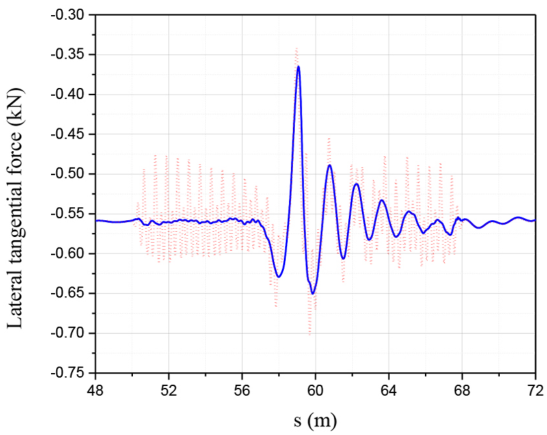


Fig. 4 Rear wheelset lateral force with lack of sleepers

(——FFR, ··········ANCF)

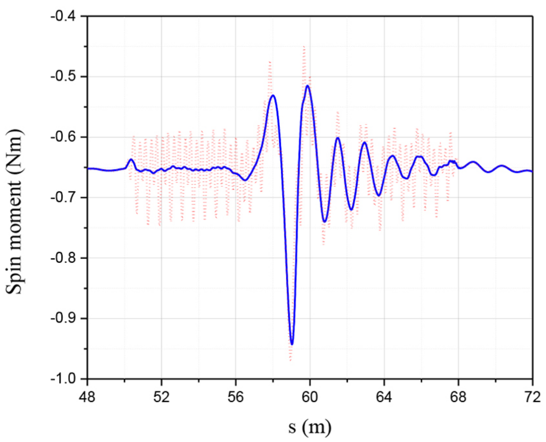


Fig. 5 Rear wheelset spin moment with lack of sleepers

(——FFR, ··········ANCF)

Summary and Conclusions

In this investigation, ANCF finite elements are used to develop a new approach for the integration of geometry and analysis for railroad vehicle system dynamics. The same shape functions used to define the rail geometry are used to perform the FE/MBS analysis. The three-dimensional wheel/rail elastic contact formulation used in this study accounts for the rail deformations and allows updating systematically the rail geometry using ANCF finite elements. Such an online updating procedure is necessary in order to compute accurately the creepages required in the formulation of the creep forces. Good agreement with the FFR approach has been found. However, because of the moving load, a high number of eigenmodes is required to achieve convergence. Despite the fact that the examples considered in this investigation represent small deformation problems, the proposed ANCF formulation can be used for large deformation problems and allows for the use of different material constitutive equations. Large deformation rail problems that result from high temperature or rail buckling will be the subject of future investigations.

References

[1]. Recuero, A.M., Aceituno, J.F., Escalona, J.L., and Shabana, A.A., 2015, "A Nonlinear Approach for Modeling Rail Flexibility Using ANCF Finite Elements", Submitted for publication.

This research was supported by the National University Rail (NURail) Center, a US DOT-OST Tier1 University Transportation Center and by the Spanish Ministry of Science and Innovation (MICINN) under Project Reference TRA2010-16715. These sources of support are gratefully acknowledged.

Amtrak's Productivity in the Northeast Corridor: Past and Future

Andrés F. Archila & Joseph Sussman
Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA

Productivity analysis, the relationship between outputs and inputs in any given process, is used to evaluate the performance of the main passenger rail services in the Northeast Corridor (NEC) during FY 2002-2012 and to make inferences about high-speed rail (HSR) for the next 30 years.

A non-parametric single factor productivity (SFP) Törnqvist trans-log index sets ridership, revenue, revenue passenger-miles (RPM) and available seat-miles (ASM) as outputs, and operating costs as inputs. According to the analysis, the NEC experienced considerable yet highly volatile productivity growth during FY 2002-2012 (in the range of 1-3% per year). Amtrak, the National Railroad Passenger Corporation, increased its ability to fill up trains and economically exploit the available capacity, but did not perform equally well on the supply side. Service changes, technical problems with train sets, targeted capital investments, and economic recession and recovery were the main drivers of productivity change. Amtrak's two primary services, the Acela Express and Northeast Regional were very sensitive to external events, had large economies of scale, and implemented slow adjustment of capacity via rolling stock and infrastructure improvements, which varied depending on the service.

Inferences about future productivity were based on Amtrak projections for the post-2012 period. The geographic and socioeconomic characteristics of the NEC reveal a potential for a successful introduction of HSR. But while Amtrak's vision for HSR in the NEC is realistic in terms of productivity gains, it is risky and possibly inadequately ambitious in terms of speed of implementation. Revising the current projections to make them more aggressive, incorporating additional planning approaches, accelerating key stages of Amtrak's vision, and coordinating with the FAA in the planning process may improve the implementation of HSR in the NEC.

The NEC from 2000 to 2012

The Northeast Corridor (NEC), stretching from Washington, D.C., to Boston, MA, is the most densely settled region and one of the economic engines of the country. The NEC is a complex multi-state, multi-operator, multi-use, and multi-owner railway corridor. It runs through several major metropolitan areas, 12 states and the District of Columbia, and involves eight commuter operators and one intercity travel operator (Amtrak).

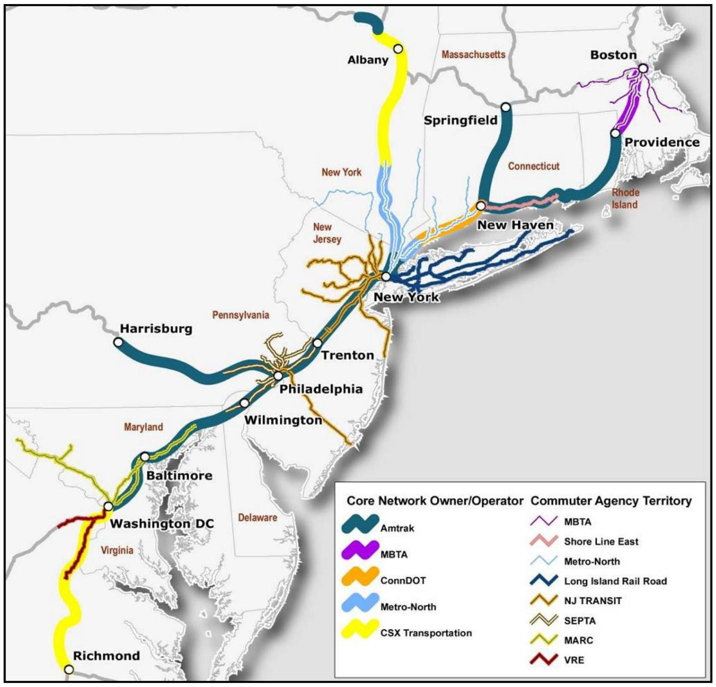


Figure 1. NEC Ownership and Operations [1]

Besides the NEC as a whole, two Amtrak services are the subject of study: the Acela Express and the

Northeast Regional (NR). Average operating speeds are 70-80 mph for the Acela and 60-65 mph for the NR, and total travel time is 6 ½ and 8 hours, respectively, from Boston to Washington.

The period from 2000 to 2012 was characterized by regional congestion, increased rail transportation demand, route changes in 2005-06, technical problems with Acela trains in 2002 and 2005, economic recession in 2008-09, and allocation of federal funding for capital investments since 2009. In this period, the capacity-constrained NEC gained significant air/rail market share and operational surplus, with a particularly profitable Acela and increasingly utilized NR, but maintenance backlogs and infrastructure constraints remained.

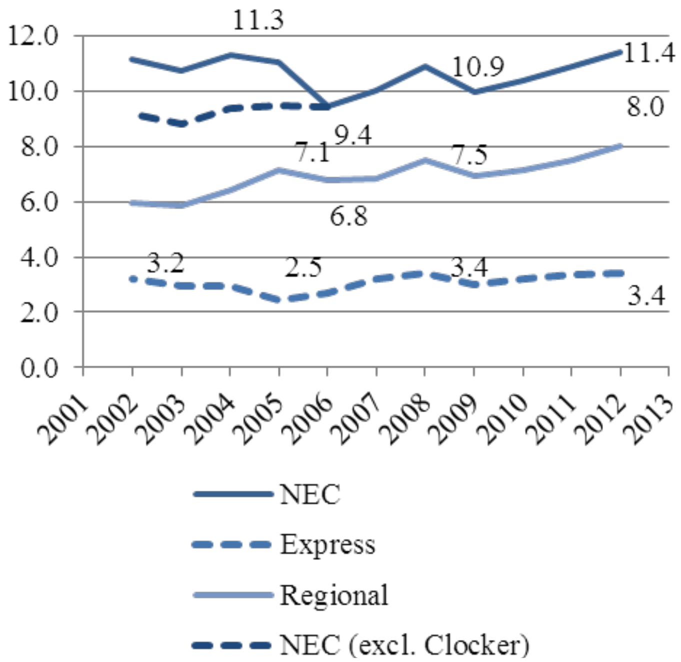


Figure 2. NEC Ridership (million passengers) [2]

Productivity Methodology

Productivity is, at the most fundamental level, a relationship between outputs and inputs used to evaluate the performance of an entity such as a country, industry, firm, system or process. Its popularity among researchers is due to the possibility of explaining the long-term growth of an entity, as well as the sources of growth. Of interest are the factors behind such a change in productivity, the drivers of productivity, which can be classified as technological change, organizational change, and externalities.

This research uses Single-Factor Productivity (SFP), which simplifies the analysis to a single-output single-input process.

Output and input data were reported by Amtrak. The available outputs were ridership, (ticket) revenue, revenue passenger-miles (RPM), and available seat-miles (ASM). The available inputs were operating costs. Monetary quantities were inflated by the corresponding CPI to 2012 dollars.

As there is only a single input but four distinct outputs, four SFP metrics were used to strengthen and validate the analysis, each providing different insights: On the supply side, ASM SFP with respect to operating costs is a proxy for the effectiveness at generating transportation capacity; on the demand side, ridership, revenue, and RPM SFP with respect to operating costs are measures of the effectiveness at exploiting the available capacity. Revenue SFP with respect to operating costs, in particular, reflects how effective Amtrak was at economically exploiting the available capacity.

Each year-to-year SFP metric was calculated via a non-parametric Törnqvist trans-log index, and then compounded to obtain the cumulative SFP, with 2005 as the base year for all calculations. Finally, a sensitivity analysis with respect to the route definitions and the inflation parameters showed that results were robust to changes in key assumptions.

NEC Productivity 2002-2012

As shown in Figure 3, from FY 2002-2012, the NEC experienced highly volatile but overall considerable SFP growth (in the range of 1-3% per year), which was boosted by the notable SFP improvements of the past three years.

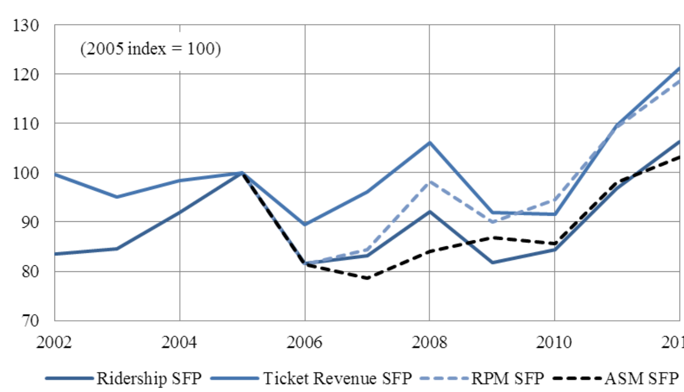


Figure 3. NEC Cumulative SFP Growth FY 2002-2012 [2]

The differences in demand-side (RPM SFP) and supply-side (ASM SFP) productivity metrics show that Amtrak increased its ability to fill up and economically exploit the available capacity, but did not perform equally well on the supply side. Service changes, technical problems with trains, targeted capital investments, and economic recession and recovery were the main drivers of productivity change. For example, the technical problems of 2005-06 and the economic recession of 2008 resulted in yearly productivity dips as low as -19%, while the recent surge in ridership and allocation of funding produced increments as high as 20%.

Acela and NR services were very sensitive to external events, had large economies of scale, and implemented slow adjustment of capacity, but their performance was not uniform. Acela was more sensitive than NR to changing conditions.

As far as productivity concerns go, the ability to implement and operate HSR in the NEC was more tied to the state of the regional economy, and less to managerial and operational practices.

Inferred NEC Productivity 2012-2040

For studying future productivity, a scenario of analysis for 2012-2040 was based on Amtrak's Vision for HSR in the NEC [3]. This is a proposed $150-billion stair-step phasing investment strategy with two sequenced programs: the NEC Upgrade Program (NEC-UP), which would reach top speeds of 160 mph, and the NEC Next Generation HSR (NextGen HSR), which would reach top speeds of 220 mph and reduced travel time to 3 hours from Boston to Washington.

The six stages of the program are:

(1) 40% additional capacity of the Acela Express achieved through additional passenger cars by 2015.

(2) Doubling of the HSR frequencies from New York to Washington by 2020.

(3 - 4) Improved and expanded service on the entire alignment, thanks to the Gateway program, track improvements, and additional HSR trains by 2025.

(5) Completion of the New York-Washington NextGen HSR segment by 2030.

(6) Full establishment of the Boston-Washington NextGen HSR service by 2040.

In this scenario, the available (projected) outputs are ridership and revenue, while the inputs are operating costs.

By 2040, the NEC could become 20–40% more productive (on the demand side) with respect to 2013. The expected yearly average growth in ridership (0.7%) and revenue SFP (1.3%) would be within the ranges of what the NEC achieved in the past (~0.5%–3.0%), though perhaps on the low side. Productivity increments would be highly variable and most likely occur in later stages. Peak changes, however, are within the ranges of productivity gains or losses that the NEC showed in the past: +/- 13–18% on peak years.

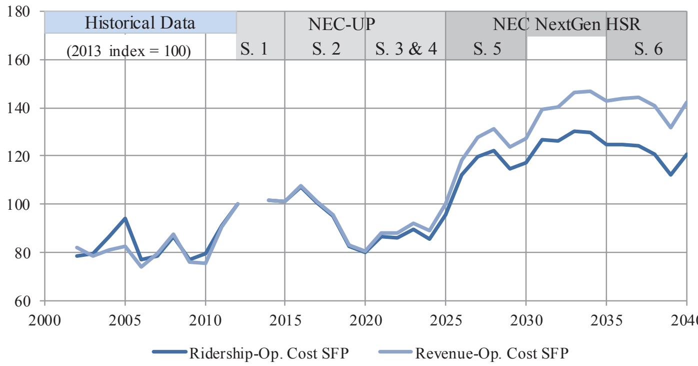


Figure 4. NEC Cumulative SFP Growth 2002-12, 2013-40 [2]

However, there are some risks. Since productivity benefits may take years to realize, and if financial leverage and political support are lacking during adverse times, or if the market and managers are slow in adapting to changing conditions, the successful implementation of HSR is uncertain.

Moreover, the NEC VISION lacks ambition in some ways, since projected cumulative productivity growth is low in comparison to the growth of the past decade (20-40% in the next 30 years vs. 20% in the past 10). Also, the plan to improve management is not explicitly mentioned, but improved management within Amtrak and coordination with other major travel modes may reveal a greater potential for productivity improvements.

Thus, we offer the following recommendations to decision-makers: revise projections of ridership and revenue; involve the FAA in the planning process and consider air/rail cooperation explicitly; consider the possibility of improved management practices within Amtrak and other stakeholders of the NEC; prioritize stages of the implementation that promise the highest productivity improvements, e.g., the Gateway Program; and use scenario planning and design flexibility in the investment alternatives.

References

[1] The NEC Master Plan Working Group (MPWG) (2010). The Northeast Corridor Infrastructure Master Plan.

[2] Archila, A. F. (2013). Intercity Passenger Rail Productivity in the Northeast Corridor: Implications for the Future of High-Speed Rail (S.M. in Transportation, MIT)

[3] Amtrak (2012). The Amtrak Vision for the Northeast Corridor: 2012 Update Report.

The authors would like to thank NURail, the Speedwell Foundation and Shelter Hill Foundation for sponsoring this research.

UNDERSTANDING CRUDE OIL TRANSPORT STRATEGIES IN NORTH AMERICA

S. Joel Carlson, Massachusetts Institute of Technology
Joseph M. Sussman, Massachusetts Institute of Technology

On July 6, 2013, an oil-laden unit train derailed and exploded in Lac-Mégantic, Quebec, killing 47 people and levelling its downtown. Following a dramatic increase in crude oil shipments on US Class I railroads from just 9,500 carloads in 2008 to 234,000 in 2012 (AAR 2013), this accident shocked many and led to the significantly increased public scrutiny of crude oil by rail (CBR).

Simultaneously, there has been intense scrutiny of several proposed pipelines from the oil sands of northern Alberta to the west and east coasts of Canada as well as to the US Gulf of Mexico Coast (USGC) (Figure 1). Pipeline opponents are concerned not only about negative potential environmental impacts from the pipelines themselves, such as a spill of diluted bitumen (a form of crude oil to be shipped), but also about the consequences of greenhouse gas (GHG) emissions caused by the energy-intensiveness of bitumen production and refining. Proponents counter that a denial of pipeline permits by the Canadian and US governments would lead to more CBR, which they argue would not only be less cost-effective, safe, and environmentally-friendly, but also ultimately lead to the same amount of GHG being emitted from the production and refining of oil sands bitumen (e.g. Krugel 2013). Therefore, much of the debate over proposed pipelines from the oil sands hinges on whether railroads could accommodate oil production increases economically and with comparable societal impacts as the pipelines.

The stakes are high: oil sands production could increase from 1.8 million barrels per day (Mb/d) in 2012 to 5.0 Mb/d in 2035, bringing along with it both positive and negative impacts for Canada and the US. Until these impacts are considered through political and regulatory processes in Canada and the US, railroads deciding whether to invest in capacity to transport bitumen are presented with considerable uncertainty. This brief provides a qualitative overview of the factors driving this uncertainty.

Figure 1: Proposed Crude Oil Pipelines in North America (Source: CAPP 2013)

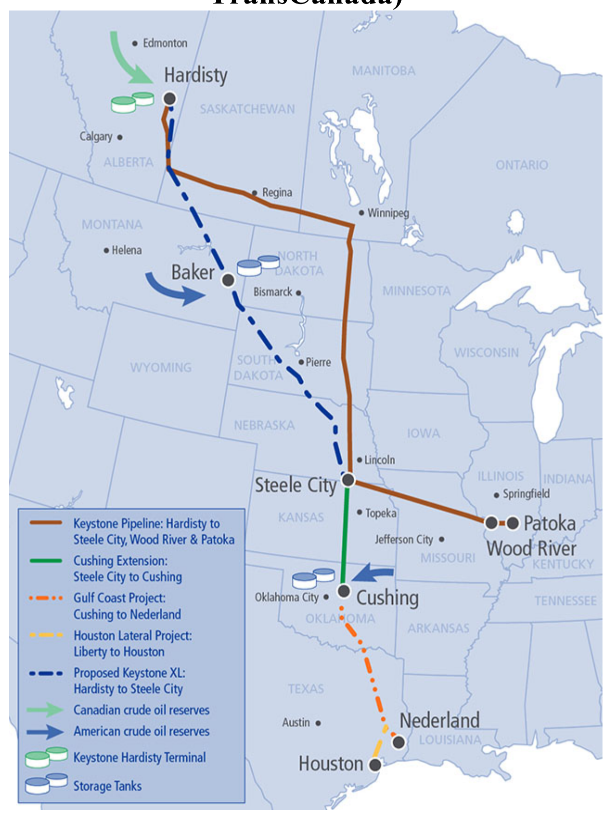
Three important impacts of oil sands production and its transportation system are: economic impacts (and relatedly energy security), GHG emissions/climate change impacts, and local environmental impacts. After describing each impact, the position of the Canadian and US governments related to these impacts will be explained. The federal governments of the US and Canada are the focus, because they hold authority over pipeline permit approval for interprovincial and international pipelines, though provinces and states have some jurisdiction over certain aspects of pipeline construction, such as pipeline "siting" in the US (Vann et al. 2012, CEAA 2012). The relative performance of railroads versus pipelines will then be described to understand how each government could favor one mode over the other to accomplish its strategic objectives, and the consequences they would need to be aware of. Throughout this discussion, uncertainties of interest to both governments and the railroads are identified.

Canada would receive significant economic benefits from oil sands production growth. Assuming plausible growth, jobs in the oil sands could grow from 75,000 jobs (direct, indirect, and induced) in 2010 to 905,000 jobs in 2035, and over this period, the Government of Canada could expect to receive $311 billion in tax revenue (Honarvar et al. 2011). As a result, all major Canadian federal political parties support (at least some of) the capacity expansion necessary to support oil sands production growth, though the New Democratic Party opposes pipelines solely designed to export unprocessed crude oil (Canadian Press 2013, Barton 2013).

Production from the oil sands also impacts the economy of the US through its trade relationship with Canada, but the magnitude of the benefits is a more contentious issue in the US. The oil sands sector could contribute to the creation and preservation of 465,000 jobs (indirect and induced) in the US in 2035, up from 21,000 in 2010 (Honarvar et al. 2011), but only some of the benefits are specifically tied to Alberta oil ending up in the US. Because oil is globally traded, US refiners may be able to import comparably priced oil from abroad regardless, although this would not necessarily be from an ally of the US (Levi 2009). As a result, the economic impacts in the US of a particular energy transport project are more difficult to quantify, leaving room for political debate.

For example, in the context of debate over the approval of a Presidential Permit for the Keystone XL (KXL, Figure 2)[1] – which is currently being evaluated by the US Department of State -- President Obama has downplayed the economic benefits from the project, indicating that its construction would create only 2,000 construction jobs, lower than the estimate given in the Department of State's (DoS's) Draft Supplemental Environmental Impact Statement (DSEIS) of 3,900 person-years in direct construction jobs (*The New York Times* 2013, DoS 2013). By contrast, many in Congress support its construction partly because of these same economic impacts (Energy and Commerce Committee 2013). Therefore, even when considering the more easily defined construction benefits of the KXL, there is significant debate over value of the economic benefits received from a pipeline project.

Figure 2: TransCanada Keystone XL (Source: TransCanada)



Because of the difference in the economic benefits potentially received by the Canadian and US governments, there is also divergence in their goals. The Canadian government wants a cost-effective crude oil transport system with sufficient capacity: it prefers pipelines, which are generally a lower cost mode.

Additionally, whether railroads would make the investments necessary to transport the expected 3 Mb/d in production growth is uncertain. The DoS (2014)

[1] Pipelines crossing the international borders into the US are required to have a Presidential Permit.

finds that such growth would be consistent with the capacity expansion that took place to accommodate coal production from the Powder River Basin. However, Cairns (2013) opines that handling the 3 Mb/d growth is "probably a stretch too far" for the railroads. Because of these unresolved questions and their greater comfort with pipelines, Canada is in favor of pipelines, even if railroads could plausibly handle the traffic competitively.

By contrast, from the US perspective, the desirability of the two modes depends on the prioritization of its goals. Specifically, the production and refining of crude oil derived from oil sands bitumen results in higher GHG emissions as compared to other heavy crudes refined in the US by 2 to 13% (DoS 2014). If GHG emissions reductions are the priority, then denying pipeline permits may be preferable, because rail transport generally appears less economic, and its ultimate capacity is uncertain. Notably, analysis for the DoS (2014) finds one scenario in which a denial of the KXL would result in modestly less production from the oil sands.

However, if reducing GHG emissions were the priority, encouraging a GHG-reduction policy in Canada appears to be President Obama's preferred approach: "Canada at the *source* in those tar sands could potentially be doing more to mitigate carbon release" (The NY Times 2013, emphasis added). However, Prime Minister Stephen Harper downplays the issue: "[emissions from oil sands production are] almost nothing globally" (Fitzpatrick 2013). Although Canada has a GHG emissions reduction target for 2020, Canada does not have any federal policy for GHG emissions reductions from the oil sector. Combined with expected oil sands production growth, Canada is currently poised to *increase* carbon emissions from the baseline year (2005). Though the US is also not on track to meet the same GHG emissions-reduction goal as Canada, Canada's oil and gas sector is a critical component to meeting that goal, because it represents 23% of Canadian emissions in 2011 (Demerse and Partington 2013).

The resistance by Canada to implementing carbon constraints, particularly when the US president views them as a key priority also suggests that there is greater uncertainty over how the incremental cost of rail transport could impact oil sands production growth. One proposal by The Pembina Institute (an environmentally-inclined think tank) for a $150/tonne carbon tax would result in an effective cost of $2.87/barrel (Partington et al. 2013), which is well within the price differential between pipelines and rail. That the Canadian government has not put more modest proposals in place suggests that oil sands producers could be more cost sensitive than the DoS concludes.

The choice of transportation modes also affects the amount of GHG emissions. While pipelines are generally considered more energy efficient and produce fewer GHG emissions than unit trains, some research indicates that the opposite may be true. Because the power grid in the US Midwest relies on fossil fuels, unit trains may produce fewer GHG emissions than pipelines from Alberta to the USGC (Tarnoczi 2013). Because these results conflict with the information provided by the DoS (2014), more research is needed into the lifecycle impacts of the two modes; it should not be assumed that pipelines have lesser impacts in all cases.

The *local* environmental impacts from the bitumen production have not been a critical issue in the debate surrounding transportation capacity, unlike the issue over spills from pipelines and railcars. In terms of research, Crosby et al. (2013) finds "critical gaps in the current oversight, rules and regulations, contingency planning requirements, and response capacity to address the increasing transport of oil sands products," though there is no evidence that the transport of bitumen causes more spills (Barteau et al. 2013). Despite the concerns, the Canadian Government passed legislation in 2012 to give the federal cabinet final decision-making power over whether a project subject to environmental reviews proceeds, instead of the National Energy Board (NEB), the regulator of interprovincial and international pipelines in Canada, which aligns with their overall strategy of supporting pipeline development (Hoberg 2013). In the US, President Obama has emphasized concerns over GHG, but concerns over local environmental impacts are being litigated in state courts (Bernstein 2014).

Therefore, transport safety records merit examination. Railroads have a lower spill rate but a higher rate of injury as compared to pipelines. Although railroads have a lower spill rate per ton-mile than pipelines, they have a higher incident rate. Therefore, on an environmental-impact basis, railroads perform modestly better than pipelines; yet public perception may still view railroads as less safe due to their higher incident rate. On a public safety basis, railroads have an injury rate 30 times higher than pipelines for the transport of petroleum products (though it is not clear from the cited report whether these accidents were solely related to the transport of the hazardous material) (Furchtgott-Roth 2013). As a result, the modal split between pipelines and railroads has safety implications, particularly from a public safety perspective.

More importantly, using historical data as a comparison has limitations, which is particularly of concern in the case of railroads, as they have not previously used unit trains to transport oil. This historical data does not include recent accidents involving crude oil, particularly the accident at Lac-Mégantic, in which approximately 38,000 barrels of oil was released (Beaudin 2013), almost double the amount of oil released (20,600 barrels) in the largest inland pipeline spill in the US (Reuters 2013). The chair of the Transportation Safety Board of Canada also emphasizes these concerns: "In this new environment, it is no longer enough for industry and government to cite previous safety records or a gradual, 20-year decline in the number of main-track derailments" (Tadros 2013). Therefore, public safety is an impact that needs to be mitigated if rail is to take a greater role in transporting crude oil, and new approaches to identifying hazards will be necessary to deal with such a major operational change.

Ultimately, whether President Obama, with the aim of reducing GHG emissions, justifies denying pipeline permits (i.e. the KXL) because it may constrain oil sands production is a value judgment in a political context. If he does so, he should also address the rail safety implications in his policies. However, because the performance of railroads is comparable to pipelines (though uncertain) along some dimensions of economic and societal importance, the consequences of denying pipeline permits on GHG emissions, economic, and other environmental impacts are not as great as often presented in the political debate. As President Obama's deliberations unfold, as well as the evaluation process for pipelines in Canada, railroads are presented with considerable uncertainty.

AAR. 2013. "Moving Crude Oil by Rail." http://goo.gl/SqLrZ9

Barteau, Mark A. et al. 2013. "Effects of Diluted Bitumen on Crude Oil Transmission Pipelines". Special Report 311. National Academies Press.

Beaudin, Monique. 2013. "Lac-Mégantic Oil Spill Even Worse than First Feared, Investigation Shows." *Montreal Gazette*. October 22. http://goo.gl/cRJQVf

Bernstein, Lenny. 2014. "Nebraska Judge Strikes down Legislature's Move Allowing Keystone XL Route." *The Washington Post*, February 20. http://goo.gl/XmSBBt

The Canadian Press. 2013. "Trudeau Praises Alberta Premier for Keystone Lobbying." *The Globe and Mail*. May 3. http://goo.gl/Iv7uOH

Cairns, Malcolm. 2013. "Crude Oil By Rail - Part I and II: Potential for the Movement of Alberta Oil Sands Crude Oil and Related Products by Canadian Railways." In Halifax, NS: Canadian Transportation Research Forum (CTRF).

Carey, Julie M. 2013. "Rail Emerging as Long-Term North American Crude Option." *Oil & Gas Journal*. August 5. http://goo.gl/GOR7tJ

Canadian Environmental Assessment Agency (CEAA). 2012. "Acts and Regulations - Canadian Environmental Assessment Act, 2012." *CEAA*. July 6. http://goo.gl/JTy6ky

Demerse, Clare, and P.J. Partington. 2013. "Context for Climate Action in Canada". The Pembina Institute.

Fitzpatrick, Meagan. 2013. "Keystone XL Pipeline 'Needs to Go Ahead,' Harper Tells U.S." *CBC News*. May 16. http://goo.gl/aZbth3

Furchtgott-Roth, Diana. 2013. "Pipelines Are the Safest for Transportation of Oil and Gas". No. 23. Issue Brief. Manhattan Institute for Policy Research.

Honarvar, Afshin et al. 2011. “Economic Impacts of New Oil Sands Projects in Alberta (2010-2035)”. Study No. 124. Calgary, Alberta: Canadian Energy Research Institute.

Krugel, Lauren. 2013. “TransCanada Warns Keystone XL Denial Would Mean More Oil by Rail.” *CBC News*. November 19. http://goo.gl/818T4s

Lattanzio, Richard K. 2013. “Canadian Oil Sands: Life-Cycle Assessments of Greenhouse Gas Emissions”. Washington, DC: Congressional Research Service.

Levi, Michael A. 2009. “The Canadian Oil Sands: Energy Security vs. Climate Change”. Council Special Report No. 47. Council on Foreign Relations.

National Energy Board. 2013. “Canada’s Energy Future 2013: Energy Supply and Demand Projections to 2035”. Calgary, Alberta: National Energy Board.

The New York Times. 2013. “Interview With President Obama.” *The New York Times*, July 27, sec. U.S. / Politics. http://goo.gl/Twqj25

Partington et al. 2013. “Getting on Track to 2020: Recommendations for Greenhouse Gas Emissions in Canada’s Oil and Gas Sector”. The Pembina Institute.

Reuters. 2013. “Factbox: Recent North American Oil Pipeline Spills.” *Reuters*, October 10. http://goo.gl/04Szca

Tadros, Wendy. 2013. “After Lac-Mégantic, the Rail Industry Needs a Seismic Shift on Safety.” *The Globe and Mail*. October 16. http://goo.gl/QnDEle

US Department of State (DoS). 2013. “Draft Supplementary Environmental Impact Statement (DSEIS) for the Keystone XL Project”. Washington, DC.

US Department of State (DoS). 2014. “Final Supplemental EIS for the Keystone XL Project (FSEIS)”. Washington, DC.

US House of Representatives Energy and Commerce Committee. 2013. “Keystone XL: #TimeToBuild.” *Energy & Commerce Committee*. August. http://goo.gl/CSMNpJ

Vann, Adam et al. 2012. “Proposed Keystone XL Pipeline: Legal Issues”. Washington, DC: Congressional Research Service.

Elasto-Viscoplastic Modeling of Rail Ballast and Subgrade

Mohammad Hosein Motamedi and Craig Foster

Department of Civil and Materials Engineering, University of Illinois at Chicago, 842 W. Taylor St, Chicago, 60607, United States of America

Settlement of Rail Ballast, Subballast is a major issue in the rail industry. Differential settlement can lead to decreased ride quality, increased wear, and, if left unchecked, derailment. Bridge approaches and other areas of non-uniform settlement are of particular interest. Most simplified models of this rail substructure do not account for permanent deformation. In this research, we develop a three-invariant soil model capable of simulating the settlement of soil under repeated loads. This model can be incorporated into finite element analysis of soils under the dynamic motions of trains.

Introduction

Under dynamic train loadings, ballast and sub-grade layers accumulate both recoverable and unrecoverable deformation vertically. The increase of unrecoverable deformation would impose considerable settlement and probably consequent stability problems for railroad track structure. The Finite Element Method (FEM) is a reliable technique for analysis and performance of the track substructure.

In order to more accurately simulate the mechanical behavior of soil layers that interact with rails, three-invariant elasto-viscoplasticity cap model is adopted. This model is based on the concepts of combined isotropic-kinematic hardening and non-associated plastic flow rule of earthen materials.

Viscoplastic modeling is critical to capture the potential settlement of the material over time, as well as the damping properties of the track substructure.

Soil Model

Soils typically yield in shear under friction, though at high mean stresses compactive failure related to pore collapse and grain crushing may occur.

A three-invariant, rate-dependent, non-associative cap plasticity model is developed to simulate the substructure materials. The model is a modified version of the Sandia GeoModel and comprises a nonlinear shear limit-state surface as well as elliptical compression and tension caps [1-3]. The viscoplasticity is taken into account using the type of overstress model originally proposed by Duvaut and Lions [4].

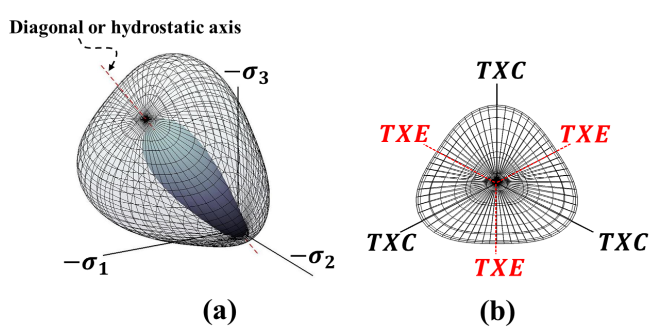


Figure 1. Yield surface of the model in principal stress space, showing difference in triaxial extension and compression strength

A modified tension cap is also added for cohesive subgrade soils, i.e. clayey soils. An efficient numerical implementation has been created to reduce simulation times and improve robustness.

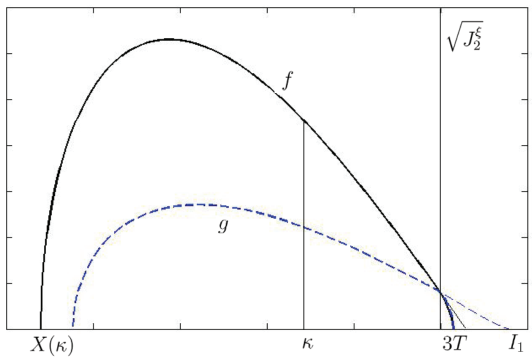


Figure 2. Yield surface and plastic potential in meridional stress space, showing tension cap (bold curve at right)

Numerical Examples

Several examples are run to test the properties of the model. Increasing the viscosity creates larger stresses under loading:

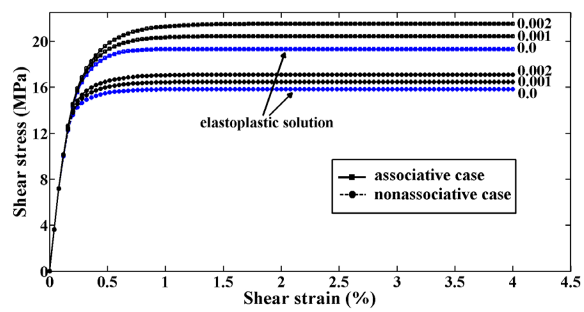


Figure 3. Effect of viscosity parameter on stress-strain response

A combined compression/ shear example tests the algorithm robustness and performance.

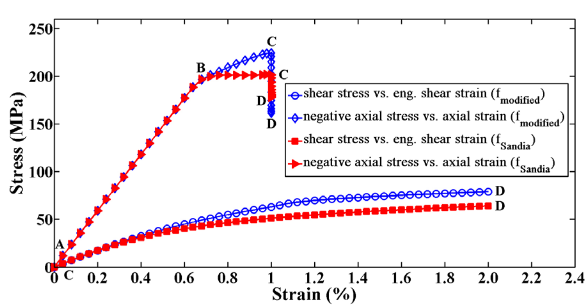


Figure 4. Stress strain plot of modified model under combined compression and shear

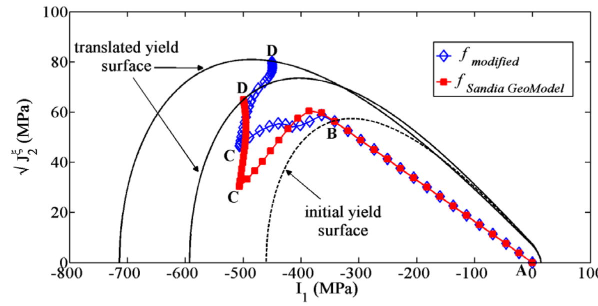


Figure 5. Combined compression/shear example in meridional stress space.

Summary and Conclusions

In summary, an advanced material model has been created to measure the transient and permanent deformation of soil under dynamic loading. This model can be implemented in finite element software for measuring settlement of the rail substructure under repeated loading.

References

[1] Motamedi, M. H., Foster, C. D., (2015), "An improved implicit numerical integration of a non-associated, three-invariant cap plasticity model with mixed isotropickinematic hardening for geomaterials" International Journal for Numerical and Analytical Methods in Geomechanics, In Press.

[2] C.D. Foster, R.A. Regueiro, A.F. Fossum, and R.I. Borja. (2005), "Implicit numerical integration of a three-invariant, isotropic/kinematic hardening cap plasticity model for geomaterials" Computer Methods in Applied Mechanics and Engineering, Vol. 194, Nos. 50-52, 5109-5138.

[3] Fossum AF, Brannon RM. (2004), The Sandia Geomodel: Theory and User's Guide. *SAND2004-3226*, Sandia National Laboratories.

This research was supported by the National University Rail (NURail) Center, a US DOT-OST Tier1 University Transportation Center and National Science Foundation Grant NSF-CMMI 1030398. This support is gratefully acknowledged.

Coupled Rail-Ballast-Subgrade analysis of train dynamics

Ahmed El-Ghandour and Craig Foster

Department of Civil and Materials Engineering, University of Illinois at Chicago, 842 W. Taylor St, Chicago, 60607, United States of America

Ballast, subballast, and subgrade are extremely important components of the rail system that affect train dynamics, rail component wear, and vibrations in surrounding buildings, among other areas. In this project, we develop an integrated multibody dynamics and finite element model that include wheel-rail contact and deformation of the rail, fasteners, ties, ballast, subballast and subgrade. The wheel-rail interaction is governed by floating frame of reference mutlibody model. A modal representation of the substructure is input into the multibody code to determine the stiffness and damping of the system. A wheel set is simulated and the deformation is examined. This phase of the research focuses on the effect of the substructure on the stiffness and damping properties of the rail and wheel.

Introduction

Support conditions greatly affect the performance rail systems, and hence the track substructure is of great importance to train dynamics. Ballast, subballast, and subgrade influence the stiffness and damping of the system, which can greatly affect ride quality, wear in the rail and wheels, and vibration in surrounding structures, among other issues. Many researchers have ignored the stiffness of the subgrade or used simplified spring-damper models to account for their behavior. These models are inaccurate in some situations, including bridges approaches, inclined track sections, and areas with complex soil topographies.

While multibody dynamics has been successfully used to simulate rail-wheel contact, the finite element method is an efficient way to determine structural stiffness in bodies. In this study, a floating frame of reference (FFR) multibody code is couple to existing finite element software to determine the stiffness and damping properties of the substructure. Modal decomposition is used to improve efficiency. These processes are coupled to examine the effects of the substructure on rail vibration.

Modeling and Example Problem

In this work, a finite element model is created that includes: rails and sleepers (beam elements), fasteners (spring elements) ballast, sub-ballast, and sub-grade (solid elements), as in Figure 1.

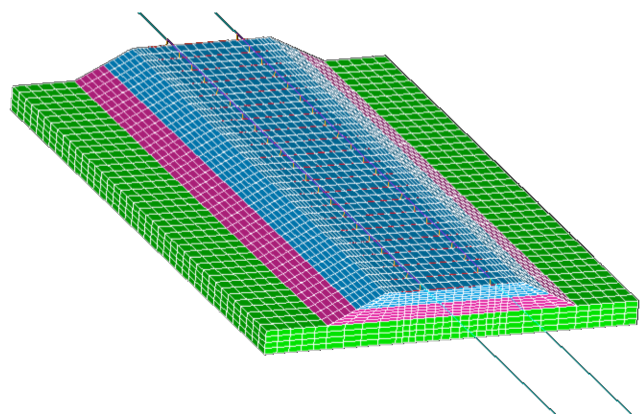


Figure 1 A 3D full FE model of the rail and substructure

The soil properties are defined as follow:
ballast: ρ=1800 kg/m^3, E=260 Mpa, v=0.25, sub-ballast: ρ=1850 kg/m^3, E=200 Mpa, v=0.35, for the sub-grade: ρ=1850 kg/m^3, E=200 Mpa, v=0.3.

For the dynamic part of the analysis, a wheelset with the following properties: Mass=1578 kg, Ixx=Izz=656 kgm2, Iyy=168 kgm2, longitudinal spring stiffness=

13,500 N/m, lateral spring stiffness=25,000 N/m, and damping= 1000Ns/m, and the running speed is 30m/s.

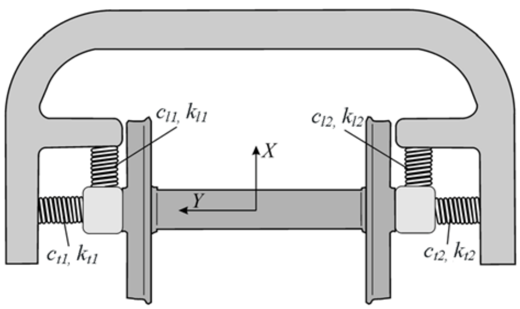


Figure 2: The dynamic analysis suspended wheelset

Numerical Results

The model presented above was compared to the literature, to test the model ability to capture the different deformations and forces. The results showed good agreements on both displacements and forces at different points on the rails with and without missing tie support. The following figures show some of the results. Figures 3 and 4 show the normal forces between the presented model and the literature work in the case of all sleepers supported and unsupported middle sleeper, respectively.

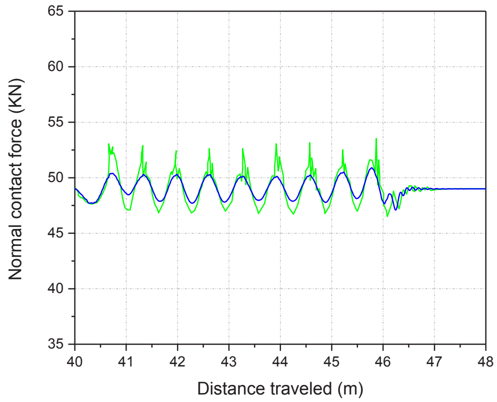


Figure 3: The contact force (Normal direction)
(FE model ——— , Literature model ———)

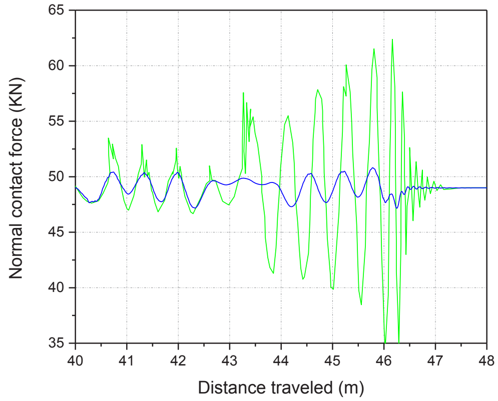


Figure 4 :The contact force for unsupported tie case (Normal direction)
(FE model ——— , Literature model ———)

Figures 5 and 6 show the vertical displacement at the center of the model, in the case of full model and the case of unsupported middle sleeper, respectively.

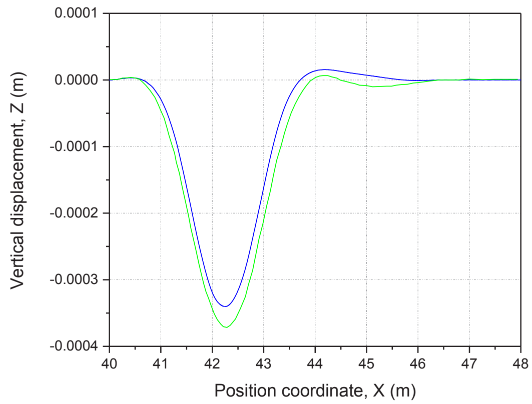


Figure 5: Vertical displacement below the unsupported sleeper
(FE model ——— , Literature model ———)

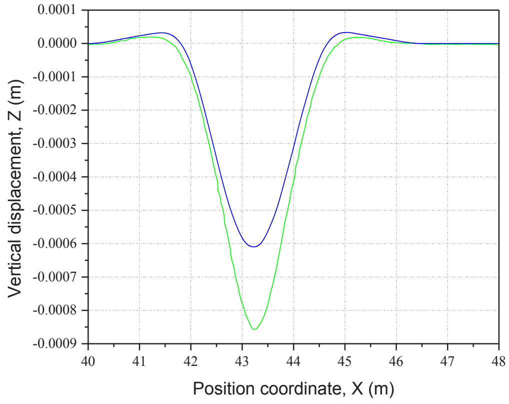


Figure 6: Vertical displacement below the unsupported sleeper
(FE model ——, Literature model ——)

Summary and Conclusions

In this work, a model of rail substructure was developed to account for the compliance and damping of vibration under trains. Compared to the literature, smoother results may be attained. This type of model can also be applied to bridge approaches, vibration in nearby structures, and other issues related to rail geotechnics.

References

[1] El-Ghandour, Ahmed I., Martin B. Hamper, and Craig D. Foster. "Coupled finite element and multibody system dynamics modeling of a three-dimensional railroad system." Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit (2014): 0954409714539942.

[2] Recuero, A. M., J. L. Escalona, and A. A. Shabana. "Finite-element analysis of unsupported sleepers using three-dimensional wheel–rail contact formulation." Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics 225.2 (2011): 153-165.

This research was supported by the National University Rail (NURail) Center, a US DOT-OST Tier1 University Transportation Center. This support is gratefully acknowledged.

Rural Freight Rail and Multimodal Transportation Improvements- The Upper Peninsula of Michigan

Michigan Technological University; Pasi Lautala, Ph.D, P.E., Gregory Graman, Ph.D., Frank Pentti, David Nelson
Student Researchers; Irfan Rasul, Akalu Tafesse, Sean Pengelly

Affordable freight transportation is a requirement for survival for many rural industries, and in many cases challenging to accomplish without the presence of freight rail systems. This study investigated the transportation system in the Upper Peninsula of Michigan (UP), concentrating on identifying challenges faced by rural freight rail service providers and shippers along light-density lines and on developing tools and methods that facilitate the current and future rail and multimodal transportation alternatives in the study area. Some of the key outcomes of the study included development of interactive rail map for the area, analysis of commodity movements and information on shipper preferences and challenges when it comes to rail. The study also provided highlights on core shipping industries in the region and on the potential to establish a joint transload facility.

Introduction

At the time of globalization, urbanization, congestion and fluctuating fuel prices, the growing importance of both freight and passenger transportation has been widely acknowledged. However, the importance of competitive transportation for rural America has received less attention. Rail is a key component of affordable freight transportation , but may rural industries are located along light-density rail lines where loss of a single shipper may negate the economic profitability of the line and lead to threat of abandonment. Without rail services, many industries would be required to consider moving their facilities to a location with better transportation alternatives.

With its 673 miles of active track, the Upper Peninsula of Michigan (UP) accounts for almost 20 percent of total track mileage in the State of Michigan. The UP is served by one Class 1 Railroad (CN) and three short-line railroads: Escanaba and Lake Superior Railroad(E&LS); Lake Superior and Ishpeming Railroad (LS&I) and Mineral Range Railroad. There is one international border connection to Canada at Sault Ste. Marie and it connects with the rail network in the State of Wisconsin, but there is no rail connection to the Lower Peninsula of Michigan

Study Tasks and Outcomes

The study consisted of six separate, but interrelated tasks. The first task consisted of the development of a proof-of-concept interactive map for the UP rail lines and facilities (Figure 1).

Figure 1. Upper Peninsula Freight Rail Interactive Map

The next task concentrated on analyzing the data on commodity movements in the UP. While the UP accounts for only 3-5% of the Michigan total truck tonnage, it is responsible for 20% of outbound rail tonnage, 4% of inbound rail tonnage and 94% of the intrastate rail tonnage. According to TRANSEARCH data, the annual tonnage (inbound, outbound and internal) moved by rail in the UP in 2009 exceeded the truck tonnage, 13.25 million versus 10.16 million tons, respectively. In addition to volumes, transportation distance was also analyzed, especially for truck movements. Almost 1,000,000 tons were trucked for over 500 miles and close to 2,000,000 million tons for over 300 miles. These movements are the likely candidates for potential modal shifts.

The third task interviewed all four railroads operating in the study area, CN, E&LS, LS&I, and Mineral Range. The forecast for future traffic by railroads was generally positive, but there are significant challenges in justifying needed maintenance expenditures on certain light-density branch lines. Railroads also advised on several service and operations related improvements they are planning to implement in the UP.

Task four developed a survey instrument to obtain input from rail and non-rail shippers. Of 127 surveys, the largest representation came from the manufacturing industry, followed by logging and service sectors. 63% of survey respondents used only truck for their freight transportation while 28% businesses use both truck and rail. The overall outlook on rail volumes was positive, as a great majority of companies reported either steady or increasing rail usage over past three years and for the next three years. The greatest challenges for increased rail shipments were related to issues with rail service or access. Majority of shippers made their shipping decisions internally, but they also recognized possessing a limited understanding of the rail transportation (Figure 2.)

The fifth task concentrated on analyzing the concerns that railroads and shippers voiced over each other's performance. After reviewing the data, the research team noticed that most of the concerns by shippers and railroads alike circulated around same topics, but approached them from a slightly different angle. The topics were divided to nine categories;

- Equipment,
- Operations, loading/unloading,
- Infrastructure/utilization,
- Rates & quantities,
- Intermodal/trans-loads,
- Information and customer service/communication.

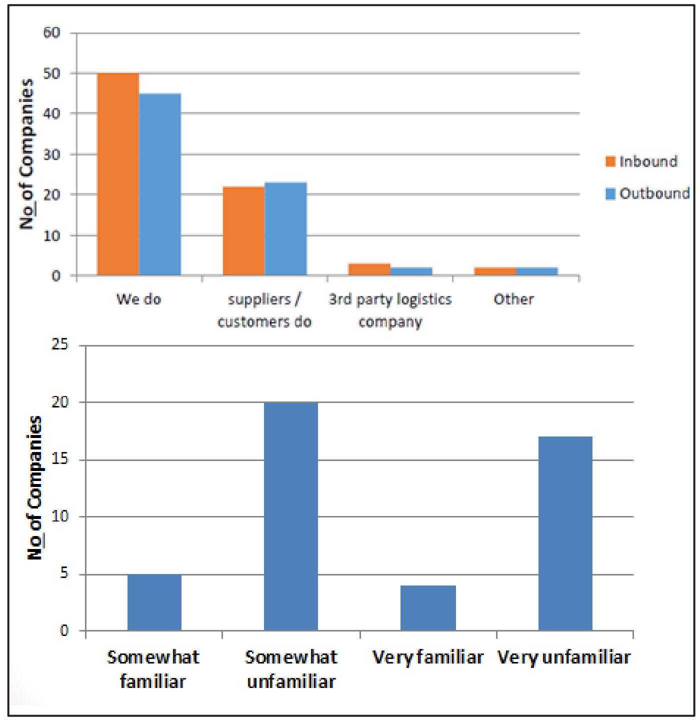


Figure 2. Shipping Decision Makers (top) and Familiarity with Rail (bottom)

The research team highlighted current activities and strategies that may improve the situation and are working with shippers and railroads to gain a deeper understanding on specific issues.

The final task concentrated on two types of case studies; current and developing businesses with potential for increased rail shipments, and potential future business areas/ventures for rail shipping. In addition, a separate study was completed to perform a three-way comparison for locating a potential transload facility. The studies revealed that mining offers highest potential for new large-scale demand. In addition, it seems plausible that sufficient volumes for a joined transload facility could be generated in the Central part of UP and even movements to adjoining states might receive cost benefits from multimodal transportation.

This work was funded by a National University Rail (NURail) Center, a US DOT---OST Tier 1 University Transportation Center and by the Michigan Department of Transportation. The research team would like to acknowledge the help and advice of:
Upper Peninsula Economic Development Agencies
Upper Peninsula Businesses and Shippers
Railroad Company Staff and Management
MDOT Staff

1st Annual Michigan Rail Conference August 27, 2013

Michigan Technological University; Pasi Lautala, Ph.D., P.E., Jessica Juntunen, Pamela Hannon, David Nelson, Sean Pengelly

The 1st Michigan Rail Conference was conducted on August 27th, 2013, in collaboration between Michigan Technological University (Michigan Tech), the National University Rail Center (NURail), and the Michigan Department of Transportation (MDOT). The objective was to promote railroad transportation, railroad education, and the role of rail transportation in economic development in the state of Michigan. Funding was provided through MDOT and NURail grant funds and revenues from conference registrations. Michigan Tech was tasked to lead the conference organization.

Introduction

The conference was co-chaired by Dr. Pasi Lautala from Michigan Tech and Nikkie Johnson from MDOT. The Chairs were responsible for guiding the organization team in all aspects of the conference, such as speaker and space arrangements, marketing aspects, registrations, etc. Chairs were supported by personnel at Michigan Tech and MDOT.

The development of content relied on two activities, implementation of an online pre-conference survey and establishment of a Content Selection Committee. The survey was distributed to the stakeholders/prospective attendees of the conference via the conference web site. The objective was to help the content selection committee to gauge the amount of interest in either passenger or freight rail transportation and rank specific topics that received most interest.

The Content Selection Committee was established from volunteer industry experts to lead the program development and recruitment of speakers to the conference. The committee also assisted in marketing the conference and in collecting presentations and biographical information from the speakers. The Committee consisted of:

- Jon Cool - Michigan Railroads Association
- Ron DeCook - DeCook Governmental Policy & Strategies
- Tim Fischer - Michigan Environmental Council
- Dennis Neilson - Michigan State University
- Nikkie Johnson - MDOT (Conference Co-Chair)
- Pasi Lautala – Michigan Tech (Conference Co-Chair)

Conference Co-Chairs with Keynote and Plenary Session Speakers

Program and Participation

The conference that took place in Lansing Community College was conducted as a single day event and was also webcast live for those who wanted to attend but were unable to be at the conference site. Conference had 113 in-person attendees, 33 real-time webcast attendees, and 29 speakers. In addition, Michigan Tech had a team of six people to handle the coordination on site and two IT professionals to handle the live web broadcast. The presentations were also published on a Michigan Tech controlled web site for later viewing.

1st Annual Michigan Rail Conference Participants

The content of the rail conference included wide range of presentations and speakers, including government agencies, educational institutions, railroad companies, railroad shippers/receivers and various rail project groups. The morning session included plenary presentations on the state of rail in Michigan, safety update by the Federal Railroad Administration (FRA) and progress update from OneRail Coalition. Also included in the first half of the conference was a panel discussion on the impact of rail transportation on economic development which allowed for interaction, as a whole, between the attendees and the panel speakers.

The afternoon program was divided between passenger rail and freight rail sessions. This format of content was intended to allow for industry component-specific attendees to view presentations that had the most relevance to their own interests as well as interact with individuals within the same interest group. For attendees with interests in topics pertaining to passenger and freight, the speaker's presentations were timed to allow for the attendees to shift from section to section in order to view various presentations.

Conference Outcomes and Feedback

The feedback on the rail conference was collected via post-conference survey sheets. The one page surveys were distributed at the end of the conference to all the attendees and speakers and most were returned upon their exit from the conference center. Eighty percent of the participants (90 of 113), excluding speakers and organizers, completed the survey. The questions in the survey covered a broad range of concepts, including top interests, conference highlights, and suggestions for improvements in future rail conferences. The survey also asked what interest and stake the attendee had in rail development in Michigan and what persuaded them to attend the conference.

The overall feedback from the attendees was positive. The level of interest was fairly equally divided between passenger and freight rail, but networking opportunities were also highly regarded.

Panel and industry-lead discussions were considered the highlight of the conference, as shown in Figure 1. This panel discussion allowed for all attendees to participant in discussion regarding Michigan rail development, and also allowed for the beginning of networking and the sharing of ideas among individuals, companies and industries.

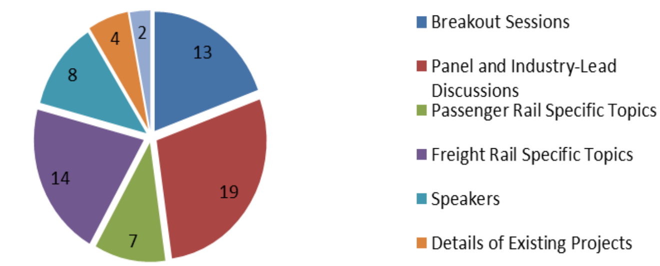


Figure 1. Conference Highlights According to Post-Conference Survey Data

Figure 2 shows suggestions for future conferences, including addition of field trips and allowing more time for networking and informal discussions. Many of these suggestions were incorporated in the 2nd Annual Michigan Rail Conference, conducted in August, 2014.

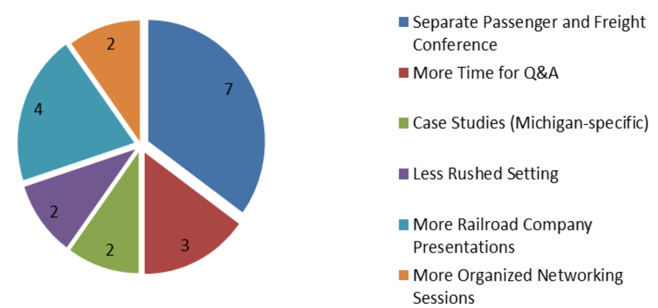


Figure 2. Suggestions for Future Rail Conferences According to Post-Conference Survey Data

RTP would like to acknowledge the efforts of the Conference Content Committee, the Speakers, and MDOT/Michigan Tech staff and students who assisted in organizing the conference.

Highway-Rail Grade Crossing Surface Material Performance

<u>NURail Project No. 2010-0295</u>

Student Researchers, Michigan Technological University; Christopher Blessing, Charles Fobbs, Nathanil Jurmu, John Klieber, Alex Summers: Faculty Advisor, Michigan Technological University, Lynn Artman, PE.

Highway-Railroad grade crossings are an integral part of the transportation system and the one location for potential conflict between road and rail traffic. Performance of the surface material at grade crossings is an ongoing challenge. A study, conducted by Michigan Tech's undergraduate students reviewed the literature available on grade crossing surface materials and crossing records available from MDOT in an attempt to determine which surface materials perform best for given traffic levels and site conditions. The study team found that the data currently available was not adequate to perform credible analysis of the situation, and developed a recommendation for a new grade crossing data collection process for MDOT. The team also made recommendations on improving the rating system used by MDOT inspectors for crossing surface condition.

Introduction

Grade crossings are a common theme throughout the United States highway network, in the State of Michigan alone there are over 4,000 documented crossings. These crossings must be maintained to provide a safe environment for both motorist and train traffic. Many high-volume crossings may see thousands of vehicles and 60-80 trains per day. This highlights the need to provide a quality structural design and maintain high safety standards. Federal Highway Administration (FHWA) standards define the required safety devices at a grade crossing, but the structure of the crossing, and the choice of surface material, is normally decided by the railroad company owning the rail line or the responsible roadway agency. The objective of this project was to evaluate different crossing surface materials and determine the one(s) that have had satisfactory performance over time.

Results

The research team selected 107 grade crossings across the state, intended to illustrate the variety of crossing surface materials in use. A visual inspection was performed, and MDOT history files were collected for each of the crossings. The MDOT history files were examined manually, and a spreadsheet was developed including the following data fields: Date of inspection; Crossing surface material; ADT; % Trucks (in ADT); Surface rating; and train speed. The crossings were divided into four categories of Concrete, Asphalt, Timber, and Rubber. A graph of inspection year vs. rating was created for each crossing from the history provided. To avoid scaling issues, the year was graphed horizontally, with each graph showing the same range, from 1994 to 2013, to cover all the data included in the history. The graphs included a vertical scale of 1-5, with integer values only, to correspond to the possible rating values.

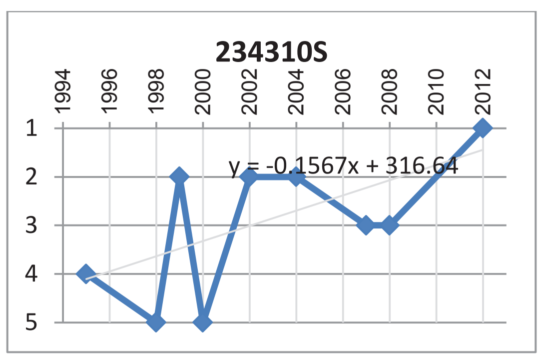


Figure 1, Inspection Rating Graph for Asphalt Crossing 234310S

The evaluation of the data and graphs led to the following conclusions:

- Very few historical records included a complete crossing life cycle from one reconstruction to the next
- Although graphs show changes in ratings, there is no causal data to go with the records, so the reasons for the changes cannot be reliably determined
- It appears that a rating change of one point in either direction for a single rating period may have no real significance. With no rating criteria two different inspectors could rate the same crossing differently on the same day.

The research revealed that shortcomings of data collection and rating process made evaluation of surface performance evaluation impossible. As a result, the team concentrated on improving the process, so institutional knowledge on performance can be improved. They developed a data collection protocol for grade crossing inspections that involves both historical research to find and document techniques during construction and collection of additional data during inspection. The protocol also includes a quantifiable inspection rating to document crossing performance across time, modeled after the PASER system developed by the University of Wisconsin-Madison (Table 1).

Table 1, Crossing Rating System for Concrete Crossings

Concrete
1 - Excellent
New Construction or Recent Reconstruction
No Defects
No Action Required
2 - Very Good
Joints all in good condition
Minor Surface defects - pop outs, map cracks
Light Surface wear
3 - Fair
First signs of crack or joint faulting up to 1/4"
First signs of joint or crack spalling
Moderate to severe scaling or polishing 25-50% of surface
Minor spalling from reinforcement
Multiple corner cracks
Fasteners loose, but not projecting above surface
4 - Poor
Severe cracking or joint faulting up to 1"
Many joints, transverse, meander cracks open, severely spalled
Extensive Patching in poor condition
Occasional holes
Fasteners loose, projecting < ¼" above surface
Loose panels, no vertical displacement
5 - Very Poor
Extensive and severely spalled cracks
Extensive failed patches
Joints failed
Restricted speeds
Loose panels, vertical displacements between panels, > ½"
Loose fasteners, projecting > ¼" above surface

Recommendations

Completing the research originally envisioned in this project will require data collection over an extended period of time. The tools developed in this project could enhance the inspection process and provide a statistically viable data set for future research efforts.

While the available data does not allow a comprehensive analysis of surface material performance, it appears that subsurface preparation impacts surface performance more than the surface material used. Some crossings from each of the categories investigated appeared to perform well over time while others failed relatively quickly.

This work was funded by a National University Rail (NURail) Center, a US DOT---OST Tier 1 University Transportation Center and by the Michigan Department of Transportation. The research team would like to acknowledge the help and advice of:
Dr. Pasi Lautala and David Nelson, Michigan Tech
MDOT Staff
Eric Peterson, CSX (retired)

Investigation on Driver Behaviors and Eye- Movement Patterns at Grade Crossings Using a Driving Simulator

Michigan Technological University; Maryam Fakhrhosseini, Myounghoon Jeon, Pasi Lautala, and David Nelson

Abstract

Collisions at grade crossings are often attributed to driver failure to detect warnings, to comprehend their meaning, or to react appropriately. One of the requirements to designing optimal warning systems is the understanding of driver perceptions and reactions when they see standard warnings at grade crossings. Since field studies are extremely time-consuming and expensive, an alternative way is to use driver simulators in a controlled environment. Michigan Tech developed three alternative scenarios at grade crossings to study the behavior. The study found that vehicle speeds of 18 participants in the period 20 seconds before approaching the crossing (critical zone) decreased in comparison to the baseline (pre-critical zone) for visual warning type 1, a gate with lights. Additionally, participants, who were exposed to a train early in the scenario, showed more defensive driving behaviors than those without early exposure. The study also investigated the drivers' eye movement pattern in the pre-critical and the critical zone to identify any differences in scanning patterns between warning scenarios.

Study 1

In study 1, 18 young drivers were asked to drive in a virtual road environment through several railroad crossings with different visual warnings (Figure 1). The first crossing was the same in all runs, and consisted of a full gate with lights plus a crossbuck sign (type 1). This crossing was used to either expose the participant to a train or not, in order to capture the effects of drivers' expectation about a train. The other railroad crossings distributed along the course included either type 1 or a standard crossing with crossbuck sign only (type 3) (Figure 2).

Figure 1. Simulator with driver

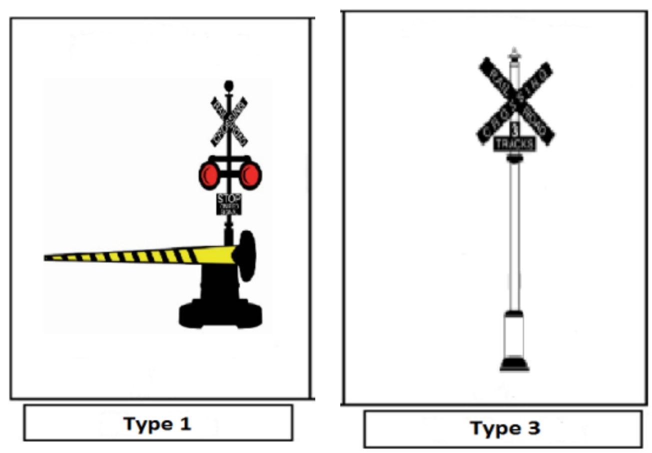


Figure 2: Warning types

The order of the crossings was fully randomized across participants, and there were at least 3.5 miles between any crossings. Data analysis was performed via custom MATLAB scripts and SPSS. The output from the driving simulator was analyzed for both the pre-critical and critical zones. "The critical zone" was defined as 20 seconds prior to the event of crossing a railroad track.

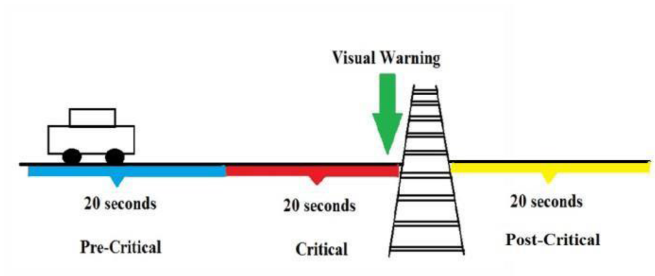


Figure 3: The pre-critical zone and the critical zone were defined for the behavior data analysis.

Study 2

Seventeen young drivers participated in this study.

In addition to the same driving data in study 1, eye-tracking data were collected via the Face Lab eye-tracker system. Each participant's eye-movement data and head rotation data were combined to create a map of where each participant was looking, with a frame rate of 60 frames/second. Data analysis was performed via custom MATLAB scripts and an SPSS package. The results from the study were analyzed for both the critical (i.e., when approaching crossings) and pre-critical zones (before crossings, i.e., baseline driving) just as in study 1.

Discussion

Active grade crossings have lower crash risks than those with passive signs. However, the cost to install and maintain active signs is considerable and likely a barrier in many areas. Therefore, it is important to assess the safety benefits of more cost-effective options. Current literature suggests that young drivers are likely to focus directly in front of the vehicle (Wann, & Swapp, 2011). However, results in this study show that the eye movement pattern might vary depending on individual differences and visual warning types. In the first study, mean speed was significantly slower in the critical zone as opposed to the pre-critical zone for visual warning type 1 (a warning gate with lights), which means that drivers slowed down because the sign was more salient than other types (lights). Also, this trend was the same for type 3, but the difference was not significant. Furthermore, the expectation of drivers for a train changed drivers' behavior significantly. Drivers who saw the train early in the scenario had lower mean speed in the critical zone, possibly because they felt there might be a train at any subsequent crossing. The idea of facing a train in the first crossing for the half of participants made the scenario more realistic. Paired samples t-tests show that drivers' speed was significantly lower in the critical zone of visual warning type 1 than type 3. This result is consistent to the literature showing that passive signs do not grab drivers' attention as well as active devices even if they are currently in the off position.

In the first study, we found a significant difference between the visual warning types. In the second study, we did not find the same differences in driving and eye movement between active and passive signs. There are two plausible explanations for this difference: First, the eye-tracking system cannot recognize the exact point that drivers are looking at, it just shows how far drivers are looking from the center along the forward visual axis. Second, the gates in the crossings were always open and lights were not flashing when there was no train present. Because there is a crossbuck, which means "yield" according to traffic rules, drivers are still supposed to look around. However, they might interpret the open gate and in-active lights as safe situations that can be driven safely without looking for a train, because they mean that no train is coming.

This project has been supported by National University Rail (NURail) Center, a US DOT-OST Tier 1 University Transportation Center.

AUTOMATIC METHOD FOR DETECTING AND CATEGORIZING RAIL CAR WHEEL AND BEARING DEFECTS

Hanieh Deilamsalehy, Timothy C. Havens, Pasi Lautala, Michigan Technological University

Worldwide, railways are among the safest transportation services. Nevertheless, every year some serious accidents are reported. A noticeable portion of these accidents is as a result of defective wheels, bearings, or brakes. Train wheels are subjected to different types of damage due to their interaction with the brakes and the track and they are required to be periodically inspected. If the wheel damage remains undetected, it can worsen and result in overheating and severe damage to the wheel and track. The most usual cause of wheel damage is severe braking, which applies directly to the wheel and results in locally heating of the wheel. This can stop the wheel from rotating while the train is still moving, producing a defect called a "flat spot." This project will focus on automatically detecting flat-spotted wheels from thermal imagery using computer vision methods. In addition to that, we introduce a novel algorithm to detect hot bearings.

Defective wheel detection methods

Train wheels are subjected to wear and different types of defects because of their interaction with the brakes and track.

A defective wheel can cause damage to both track and the vehicle. In order to identify a damaged wheel at an early stage, there are two main choices. First is costly manned inspection, which is time consuming. Furthermore, the defect may have not happened by the time of inspection. Remote automatic detection is an alternative option. This second option is faster and cheaper once all the equipment is installed. Hence, it can be done more often. For the remainder of this research brief, we will introduce our proposed algorithm for hot-spotted wheel and hot bearing detection, which increases the maintenance efficiency. Our algorithm is developed based on thermal images taken of train wheels. Some samples of thermal images taken with a track-side imaging system are shown in

Figure 1.

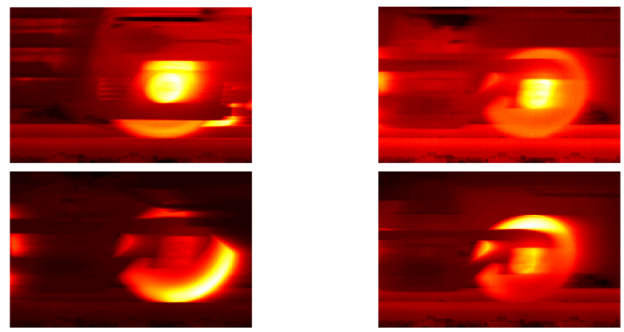


Figure 1: Thermal images taken by track-side thermal imaging system

Automatic wheel hot-spot and hot bearing detection

If there is a skidded wheel, the metal wheel heats up locally at the area of damage. To automatically detect the skidded wheel, several steps of image processing and computational intelligence algorithms are used. Figure 2 shows the block diagram of the algorithm, proposed in this research work.

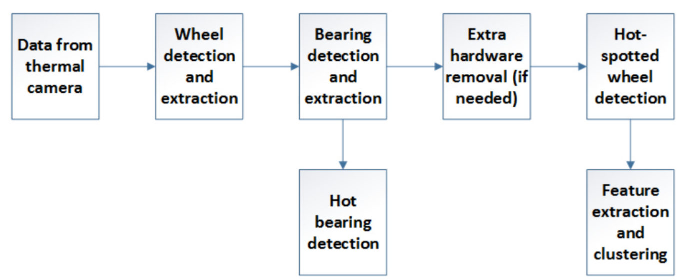


Figure 2: Automatic wheel defect detection block diagram

The steps that should be taken in order to detect the hot spot are stated next.[i]

1- Identify and segment the wheel region using Hough transform.
2- Detect and segment the bearing region out, employing the Hough Transform.
3- Hot spot detection using Bit Planes algorithm.
4- Categorize the damage level of the detected

hot-spotted wheels using a fuzzy inference system.

5- Categorize the defective wheels into one of the five different damage levels using fuzzy inference system. Level 1 is the least significant damage level and Level 5 is the most severe damage.

Figure 3 illustrates the wheel and bearing segmentation steps and Figure 4 shows the hot spot detected from a wheel thermal image by the algorithm.

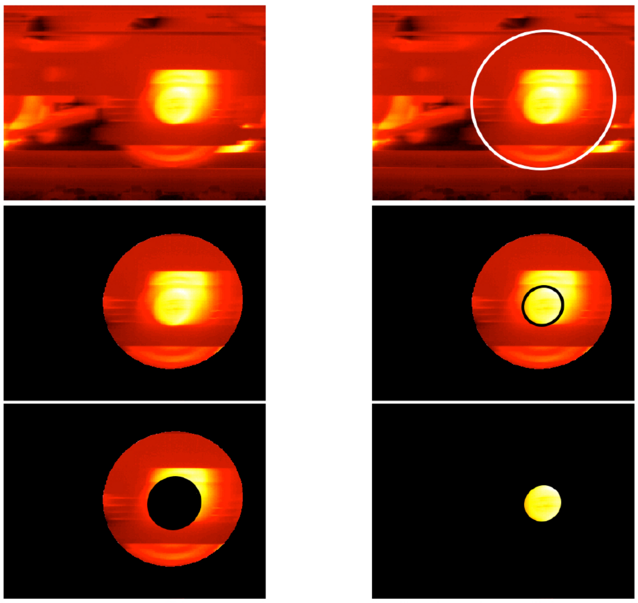


Figure 3: Image segmentation of wheel and bearing regions

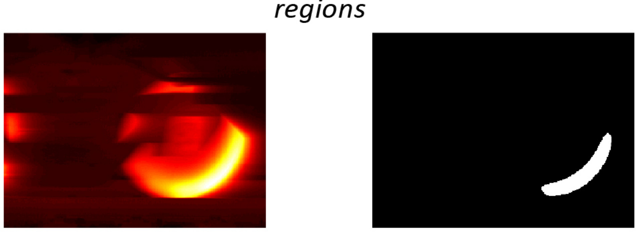


Figure 4: Hot-spot detection

If a wheel is detected with a hot spot, the severity of the damage is estimated and, based on the damage level, the proper solution should be taken.

In order to detect the hot bearing our algorithm proposes the following steps:

1- Identify the wheel outline from the original thermal image and segment the wheel region using the Hough transform.

2- Identify and segment the bearing region from the segmented wheel part using the Hough transform.

(These first two steps of algorithm are in common with the hot-spotted wheel detection algorithm.)

3- Calculate the mean intensity and temperature of the bearing.

4- Indicate the hot bearings based on a pre-determined temperature threshold.

The intensity distribution of a data set consisting of 352 wheel thermal images is shown in Figure 5 and, by knowing the threshold, we can conclude that every bearing with a temperature higher than the indicator temperature is a hot bearing.

Results and conclusion

We applied our proposed algorithm to four different data sets from a Union Pacific (UP) railroad. The four data sets contain 352, 353, 94, and 419 thermal images, respectively. Our algorithm detected 19, 28, 91 and 41 defected wheels in each data set accordingly. We also applied our hot bearing detection algorithm to the first data set consisting of 352 images. The intensity distribution of this data set is shown in Figure 5. By knowing the threshold, we can conclude that every bearing with a temperature higher than the indicator temperature is a hot bearing.

The conversion of intensity to temperature was unknown in these data; however, the histogram shows the distribution of bearing temperature accordingly.

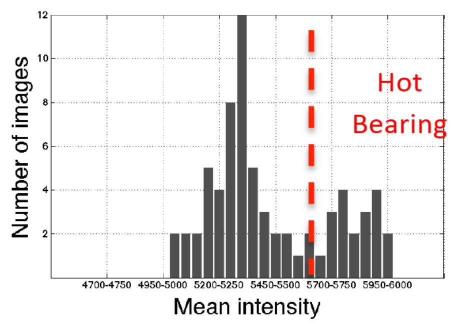


Figure 5: Bearing intensity distribution

ACKNOWLEDGEMENTS

This work was funded by a National University Rail (NURail) Center, a US DOT-OST Tier and University Transportation Center. We would like to thank Tom Bartlett and William GeMeiner at Union Pacific for providing us with data and guidance in this project.

---

[i] The detailed method can be found in our paper "Automatic method for detecting and categorizing train car wheel and bearing defects ", Joint Rail Conference (JRC), March 2015.

Flexural Behavior of High Density Polyethylene Railroad Crossties

Ibrahim Lotfy[1], Maen Farhat[1], Mohsen A. Issa[1], and Mustafa Al-Obaidi[2].

[1] University of Illinois at Chicago

[2] HBM Engineering Group, LLC.

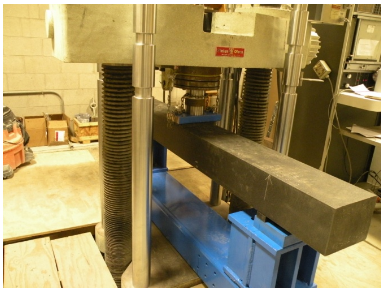
In this brief, a flexural testing program aiming to assess the performance of HDPE railroad crosstie is presented. It addressed two AREMA recommended test methods for crosstie. The behavior of the crosstie with the rail and fastening system installed was also investigated. The effect of the installation of the rail and fastening system was also illustrated and justified. Finally, the development and calibration of a material model capable of simulating the flexural behavior of HDPE crossties was presented. Highlighted below is a summary of the research program.

Problem Statement

Hardwood timber has been the predominant material of choice for crossties since the establishment of the railroad industry in the US. Recently, several concerns, including higher speeds, heavier loads, durability and negative environmental effects associated with deforestation and wood treating chemicals, have invoked the railroad industry's interest in alternative materials for crossties. Currently, several manufacturers offer alternative and sustainable solutions using different recycled plastic composite materials. Thousands of plastic crossties are currently in service in a wide variety of railroad applications. Several researchers have been studying and testing these new materials, specifically High Density Polyethylene (HDPE), however their behavior when subjected to rail loading is not fully understood yet. Uncertainties in mechanical properties, failure modes, and fracture render their performance and safety questionable. More research is required to properly characterize, describe and model the behavior of these materials as well as assess the feasibility of implementing these materials in railway applications in terms of performance, safety, practicality, and economy. Therefore, this study aimed to investigate the performance of plastic composite crossties through experimental testing and analytical modeling.

Experimental Program

Two tests from the AREMA manual were conducted; the center and rail seat bending. The rail seat bending test was performed once using the crossties with and without the rail and fastening. These configurations granted a wider view of the behavior of the crossties and allowed the determination of the effect of the predrilling and installation of the rail and fastening system on the flexural behavior of the crossties.

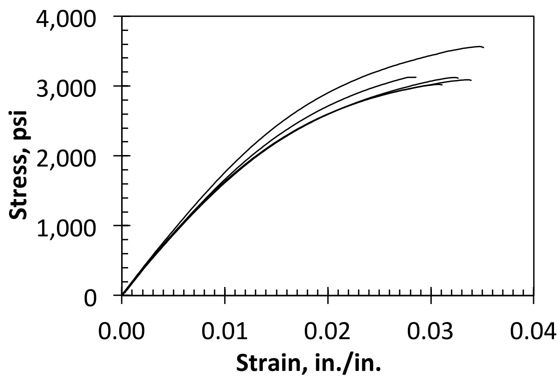


Center bending test (left) and rail seat bending with the rail system (right).

A three point test configuration was implemented. The span length was used as 60 and 30 in. for the center and rail seat bending tests respectively. The loading was applied as a concentrated load at the specimen's mid-span and a rigid reaction steel testing frame was used to properly support the specimens. The specimens were loaded until failure with a stroke-controlled rate of 1.0 in./min and a load controlled rate of 10,000 lb/min for the center and rail seat bending respectively. The mode of failure observed was a brittle fracture due to mid-span tensile bending stress. No cracks were observed at any stage of the test until failure

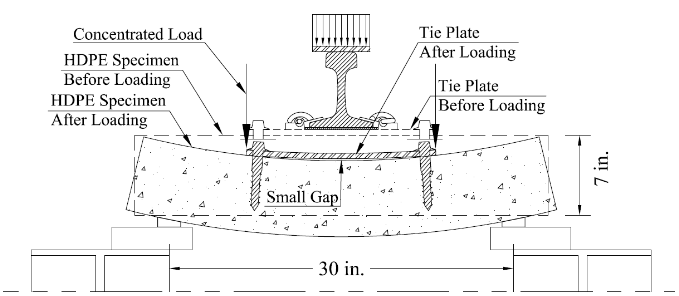
Failure of the center bending test (left) and rail seat bending with the rail (right).

The fractured surface indicated that the crossties had excellent quality cross-sections featuring few voids with few impurities, if any, and a great distribution of discontinuous glass fibers in the exterior region.



Stress-strain curve of the HDPE crossties.

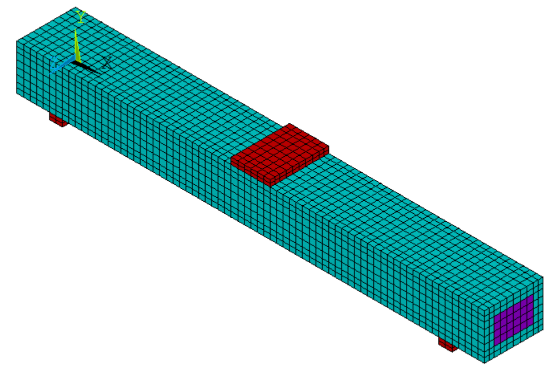
All the specimens fulfilled the AREMA recommendations for engineered composite crossties. An increase in the ultimate flexural strength was observed in the specimens with the rail system installed. This additional capacity was mainly attributed to the load distribution quality of the steel bearing plate and the partial composite action between the crosstie and the steel bearing plate.



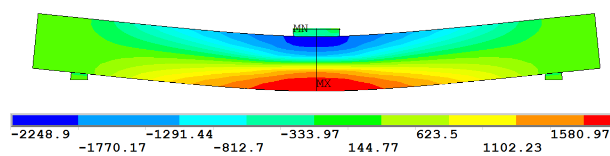
Exaggerated deflected shape illustrating crosstie/bearing plate interactions.

Finite Element Analysis

The objective of this analysis was to construct a material properties model capable of representing the HDPE crossties. The model was calibrated using the experimental data. Three different modeling approaches were calibrated and assessed in terms of accuracy, computational efficiency, and practicality. The best modeling approach was proposed for future research and applications.



Finite element model of the center bending test.



Stress distribution of the center bending specimens at failure in psi.

Conclusion

- All the tested specimens fulfilled and surpassed their corresponding AREMA recommendations.
- The installation of the rail and fastening system enhanced the performance of the crossties. This was attributed to the load distribution quality of the steel bearing plate and the partial composite action between the crosstie and the steel bearing plate.
- A detailed, nonlinear, finite element modeling approach accounting for the crossties section composition was achieved and accurately portrayed the flexural behavior and failure of the crossties.

This research was funded by the National University Rail Center (NURail) and the U.S. Department of Transportation – OST. Special thanks are directed towards Tangent Technologies, LLC and CTA for their support. The authors would like to acknowledge the contribution of Mustapha Ibrahim for helping during the testing of the HDPE specimens.

Temperature Effect on the performance of Glass Fiber Reinforced High Density Polyethylene Composite Railroad Crossties

Ibrahim Lotfy, Maen Farhat, and Mohsen A. Issa.

University of Illinois at Chicago

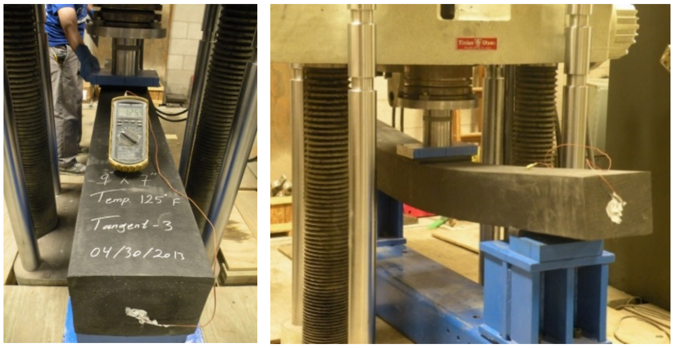
In this brief, an experimental testing program aiming to assess the effect of temperature variation on the performance of glass fiber reinforced HDPE composite railroad crosstie is presented. It employed an AREMA recommended test method for crosstie to address a practical operating temperature range from 10°F to 125°F. The effect of the temperature variation was studied for several vital performance criteria; initial modulus, modulus of elasticity, secant modulus, ultimate strain and modulus of rupture. Finally, the development and calibration of temperature scaling curves capable of predicting these vital parameters at an arbitrary exposure temperature within the investigated range was presented. Highlighted below is a summary of the research program.

Problem Statement

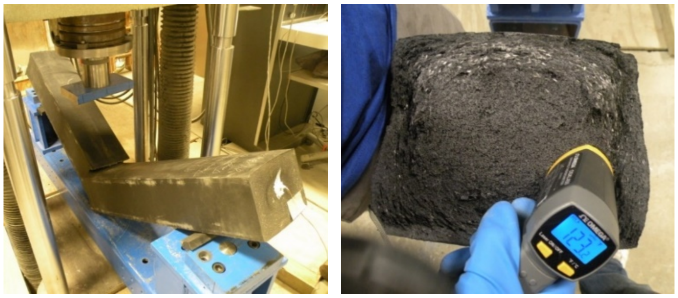
The effect of temperature on structural materials has always been a concern in engineering applications. Thermoplastic composites are highly sensitive to temperature changes and recycled high density polyethylene (HDPE) is no different. Temperature variation may alter the mechanical properties even for the best-designed HDPE compositions. Thermoplastic materials usually experience lower modulus of elasticity and higher ductility at elevated temperature conditions and higher modulus of elasticity and lower ductility at low temperature conditions. Therefore, it is of vital importance to study and fully understand the nature and extent of this effect. This knowledge will enable the safe implementation of these materials in structural applications where low or elevated temperature exposure is expected. In this study, an experimental testing program aiming to assess the effect of temperature variation on the performance of HDPE composite railroad crosstie is presented. It employs an AREMA recommended flexural testing method to investigate a practical operating temperature range; from 10°F to 125°F.

Experimental Program

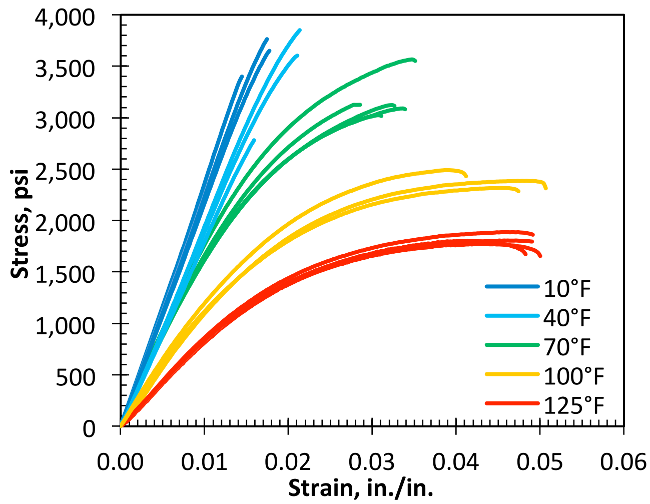
A sophisticated "Hotpack" controlled environmental chamber, at the University of Illinois at Chicago structural laboratories, was used to simulate the desired temperature prior to the testing. The temperature of the chamber was also rechecked using a digital "Weiss" thermometer for redundancy. The temperature of the crosstie specimens was monitored using another infrared "Omega" thermometer. In order to determine the temperature inside the core of the crosstie specimens, temperature-sensing probes (type-K thermocouples) were installed inside all the crosstie specimens. The test was conducted when the four temperature monitoring thermometers displayed the desired testing temperature. A 10- to 12-hour period was required to ensure that the temperature inside the core of the crosstie reached the desired testing temperature.



Flexural testing of the HDPE crossties under different temperatures.

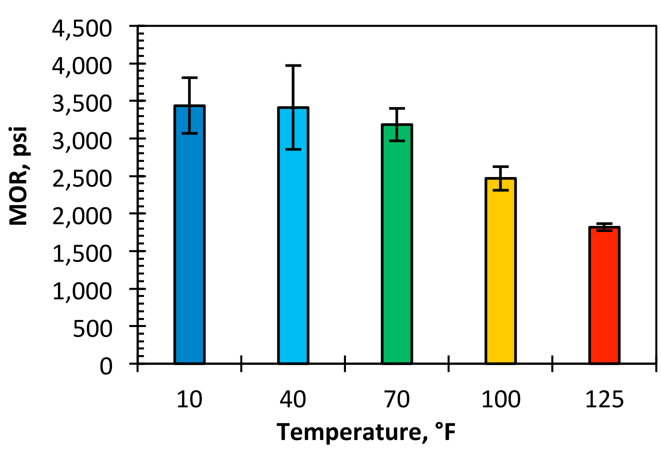


Mode of Failure (left) and measuring the core temperature after failure (right).



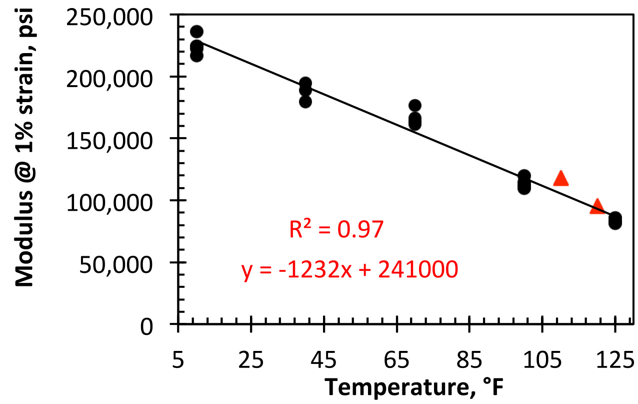
Temperature effect on the HDPE material compliance.

The specimens experienced lower stiffness and higher ductility at high temperature exposure and higher stiffness and lower ductility at low temperature exposure. Considering the room temperature as reference, at 125°F, the specimens experienced an increase of 52% in ductility and a reduction of 50% in the stiffness. However, at 10°F, they experienced a reduction of 51% in ductility and an increase of 22% in the stiffness.



MOR at the different temperatures.

The results deviation was high at lower temperatures however; it decreases significantly with the increase in temperature. This observation is significant and it was noticed in several criteria. Optimizing the fiber reinforcement content can enhance the performance of the crossties at the expected exposure temperatures.



Temperature scaling curve for the modulus at 1% strain.

Conclusion

- The stiffness and MOR of the crossties increased at low temperatures and decreases in elevated temperatures, and vice versa for the ductility. While this trend was expected, it was interesting to observe that the increase in stiffness at lower temperatures was less pronounced than its decay at higher temperatures.
- A 10- to 12-hour period was required for the core to attain the temperature of the environmental chamber. Therefore, the core temperature of the crossties will not vary significantly with normal sun exposure or day and night cycles.
- The increased ductility at higher temperatures allowed the glass fiber reinforcement to be activated earlier, thus increasing the efficiency of the fiber reinforcement.
- The temperature scaling relationships were able to predict the performance of the crossties with reasonable accuracy at arbitrary exposure temperatures within the investigated range.

This research was funded by the National University Rail Center (NURail) and the U.S. Department of Transportation – OST. Special thanks are directed towards Tangent Technologies, LLC for their support. The authors would like to acknowledge the contribution of Mustafa Ibrahim and Mustafa Al-Obaidi for helping during the testing of the HDPE specimens.

Effect of Pre-drilling, Loading Rate and Temperature Variation on the Behavior of Railroad Spikes used for High Density Polyethylene Crossties

Ibrahim Lotfy, Maen Farhat, and Mohsen A. Issa.

University of Illinois at Chicago

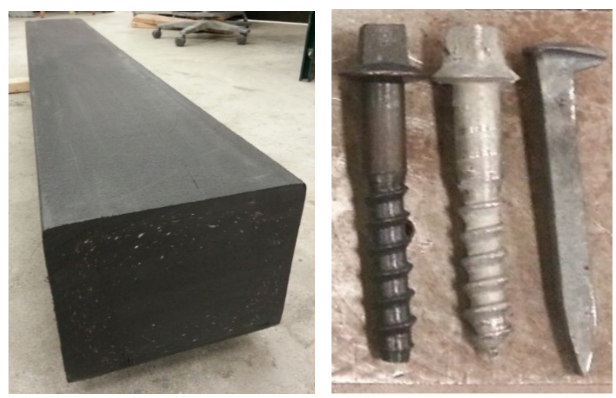
In this brief, a parametric experimental testing study aiming to assess the behavior of railroad spikes typically used with HDPE composite railroad crossties was presented. It employed static test methods recommended by the AREMA manual to address rail spike pullout and lateral restraint for both screw and cut. Finally, the development and calibration of a finite element model capable of simulating the behavior of the screw spikes and their interaction with the HDPE crossties was presented. Highlighted below is a summary of the research study.

Problem Statement

Railroad spikes represent a vital component of the rail track system as they fasten the rail to the supporting crossties. Thus, it is important to understand its behavior and effect on the fastening assembly to mitigate any local failure. Currently, alternative solutions to the traditional hardwood timber crossties are increasing being adopted by the railroad industry in the US and recycled plastic composite crossties are among the available alternatives. Several research programs have studied this material and its fastening system in the past; however, additional research is required to fully understand the behavior of these materials and their interactions with the fastening system components. This study presents an investigation aiming to understand and assess the performance of typical railroad spikes used for recycled High Density Polyethylene (HDPE) crossties. The study encompassed a comprehensive experimental investigation and analytical finite element modeling. The testing program evaluated railroad spikes using static testing methods recommended by the American Railway Engineering and Maintenance-of-Way Association (AREMA) manual. These tests addressed the rail spike pullout and lateral restraint for both screw and cut spikes. Finite element models were constructed and were calibrated using the data obtained from the experimental program in order to extrapolate on the experimental results and predict the behavior of full-scale systems beyond the scale of the laboratory.

Experimental Program

The railroad spikes used corresponded to the same spikes used for actual plastic composite crossties applications. They are manufactured from A36 steel.



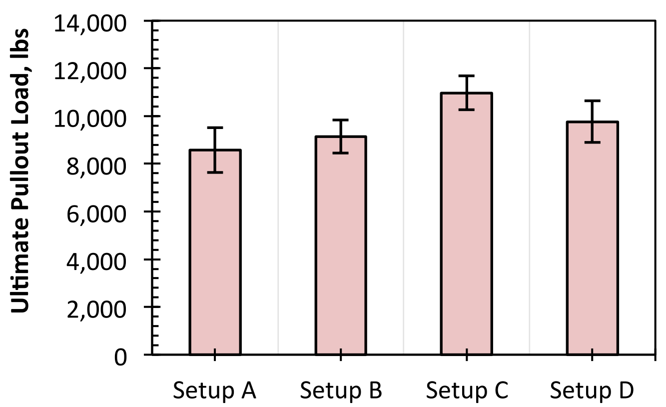
HDPE composite crosstie specimens (left) and railroad spikes (right).

The spike pullout and lateral restraint tests were performed as per the AREMA manual recommendations. The spike pullout was used to measure the ability of an embedded railroad spike to resist withdrawal from the plastic composite crosstie while the lateral restraint test was performed to identify the ability of an embedded screw spike to withstand lateral forces. All the spikes were installed manually and a total of 55 pullout tests and 5 lateral restraint tests were performed to investigate several parameters affecting the interactions between the spike and the HDPE composite crosstie including: pre-drilled pilot holes size and shape, type of spikes used, rate of loading and temperature variation. It is worth noting that all the tested specimens surpassed the minimum AREMA recommendations by a significant margin in all the tested conditions.

Spike pullout test.

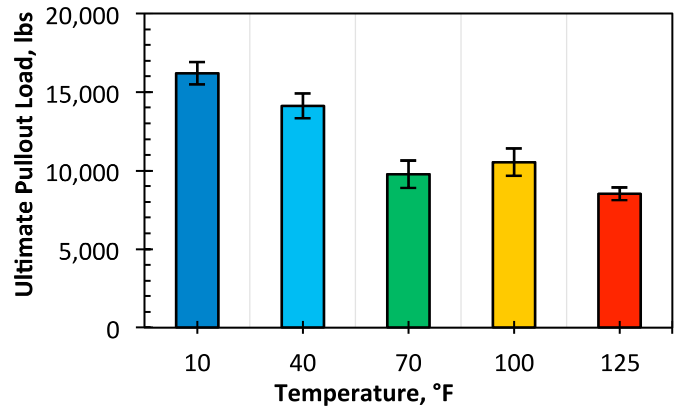
Spike lateral restraint test.

A Predrilling profile; "setup D", was proposed by the authors as it provided a good bond without causing material bulging/build-up near the spike; it tailored the actual profile of the screw spike. Cut spikes exhibited less holding power than screw spikes as expected; however, they still surpassed the AREMA recommendations.



Predrilling effect on spike pullout load.

At higher temperature, the pullout resistance remained almost constant.



Temperature effect on spike pullout load.

Conclusion

- All the tested specimens surpassed the AREMA recommendations for screw and cut spike. Screw spikes exhibited surpassed them by a significant margin (up to more than 200%) and thusly are highly recommended for future implementation.
- An optimal pre-drilling configuration was proposed for screw spikes that allowed the best holding power without introducing stress concentrations nor causing material build-up and bulging in the vicinity of the spikes. Pre-drilling did not affect the pullout capacity of cut spikes.
- The slowest loading rate produced the most conservative spike pullout resistances. Therefore it is recommended for future evaluations.
- The pullout capacity of the specimens was not negatively affected, by elevated temperatures as material softening was compensated by confinement due to thermal expansion.
- Both the crosstie and the spike acted together as a composite section when resisting lateral forces.
- The finite element model constructed showed good accuracy and correlation with the experimental results. The model was greatly optimized and refined to have optimal computational time and cost while maintaining accuracy.

This research was funded by the National University Rail Center (NURail) and the U.S. Department of Transportation – OST. Special thanks are directed towards Tangent Technologies and CTA for their support.

Experimental Testing of Totally Precast Concrete Counterfort Retaining Wall System

Maen Farhat and Mohsen A. Issa.

University of Illinois at Chicago

In this brief, an experimental investigation was carried out to understand and assess the performance of totally prefabricated counterfort retaining wall system which can be used for highway and railway applications. The system was designed to be assembled on-site with aid of headed anchors, which are grouted in the base slab to ensure connectivity. The experimental testing was designed to mimic real life loading conditions i.e. soil backfilling and live load surcharge loading to examine the performance of the wall at service limit state . The wall was then taken to ultimate loading conditions to examine the structural strength, design efficiency and failure mode of the system. Highlighted below is a summary of the research study.

Problem Statement

The main challenge in railroad bridge construction is the inability to divert railroad traffic as in highway bridges. As a result, the need for bridge components that can be constructed under fast track construction scheme, incited the idea of developing a totally precast concrete counterfort retaining wall (TPCCRW) system. TPCCRW is designed to meet the requirements of rapid construction, durability, safety, and cost for retaining walls and abutments for bridges.

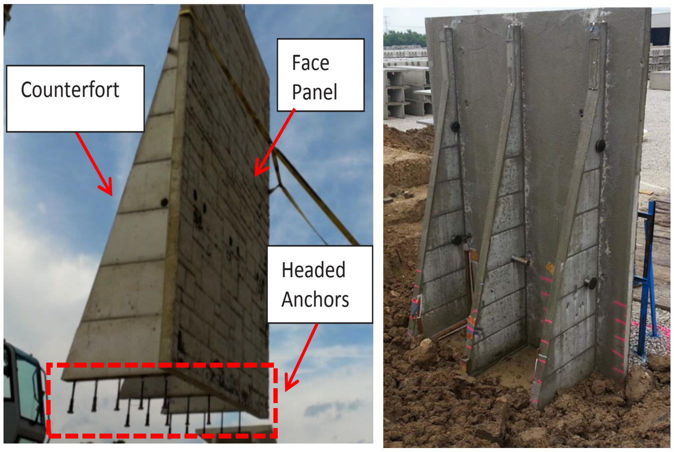
TPCCRW consists of two prefabricated entities: face panel with three counterforts, and base slab. Headed anchors are used to connect the each counterfort to base slab. TPCCRW is strengthened with counterforts which act as stiffeners connecting the wall to the base slab. It has been proven that counterfort retaining wall system exhibits enhanced serviceability when compared to conventional cantilever retaining wall systems. Scarce research was found that covers any development or optimisation for the end supports of bridges like retaining walls and abutments.

This work intends to study the applicability of totally prefabricated precast concrete counterfort retaining wall system (TPCCRW). The overall structural behavior is studied through full scale experimental testing.

The study encompassed a comprehensive experimental investigation using static test methods. The experimental test addressed the structural performance of the proposed rail support system when subjected to lateral soil pressure and live load surcharge at the ultimate load level.

Experimental Program

The experimental program is divided into four phases: fabrication, erection, instrumentation, and experimental testing phases. A 20 ft - 2 in. (6.09 m) high, 13 ft – 10 in. (4.21 m) wide full scale TPCCRW prototype was designed meeting the requirements of AASHTO LRFD and AREMA Specifications.



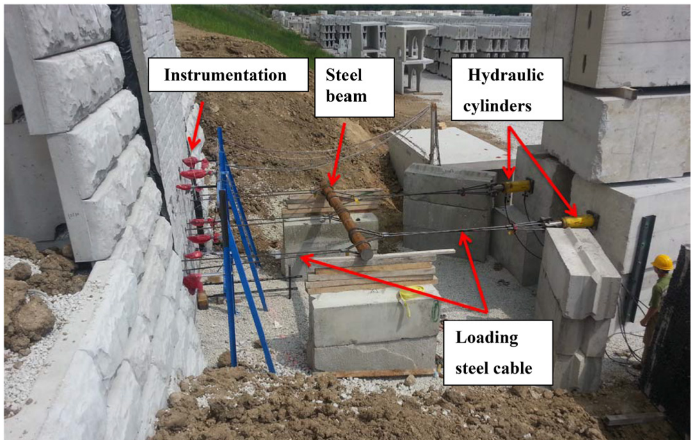
Front (left) and rear elevations (right) of the assembled wall.

The testing procedure can be summarized as following:

1. Soil Backfilling: soil pressure was applied by backfilling of the retaining wall with soil with 95% compaction level.
2. Surcharge Load: was applied using Dozers to simulate the actual condition for live surcharge.

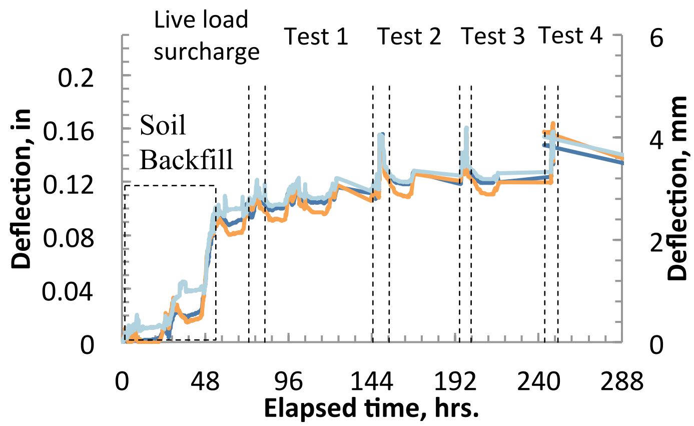
Application of live load surcharge using a 37 kip (164.6 kN) bulldozer

3. Test 1: two hydraulic cylinders applied up to 178 kips (791.78 kN) at one H/3 of the wall acting at 6 points divided over 3 counterforts. It is followed by Hydraulic actuator at the top of the wall delivering 160 kips (711.71 kN).
4. Test 2: two hydraulic cylinders applied up to 136 kips (604.95 kN) at H/3 of the wall acting at 6 points divided over 3 counterforts.
5. Test 3: two hydraulic cylinders applied up to 97 kips (431.47 kN) at H/3 of the wall acting at 2 points on middle counterfort.
6. Test 4: two hydraulic cylinders applied up to 192.4 kips (855.83 kN) at H/3 of the wall acting at 6 points divided over counterfort.



Details of the testing setup

The experimental testing results show consistent deflection values between the counterforts and the mid-spans of the wall throughout various testing times. This is due to the efficiency of the geometry in minimizing the load resisted by the face-panel where the counterforts are designed to solely resist the total applied lateral load.



Deflection results from the experimental testing

Conclusion

- Headed anchors showed excellent performance in maintaining the composite action between the precast wall and the base slab at service and ultimate loads. This was verified by the experimental testing. The deflection measured at the mid-height of the wall was found to be around 0.2 in. (5.1 mm). Counterforts added stiffness to the structure by increasing the section at which the bending moment due to the applied load is being resisted.
- Headed anchors are extended from the counterforts to the base slab. Therefore, it maintains the integrity of the system by resisting the shear forces at the interface between the wall and the base components. In addition, the anchors are also responsible for resisting the bending moment due to the applied load and transferring the load to the base slab.
- Totally Prefabricated Counterfort retaining wall system exhibits a good performance to be utilized for highway and railway applications. It satisfies the need for fast track construction.

This research was funded by the National University Rail Center (NURail) and the U.S. Department of Transportation – OST. Special thanks are directed to Utility Concrete Products (UCP), LLC. Morris, IL.

Finite Element Modeling of Totally Precast Concrete Counterfort Retaining Wall System

Maen Farhat and Mohsen A. Issa

University of Illinois at Chicago

In this brief, Three dimensional Nonlinear Finite Element Analysis (NLFEA) using ANSYS® package was developed to analyze the structural behavior of totally prefabricated counterfort retaining wall system (TPCCRW) designed for and railway applications. The purpose of NLFEA is to (1) verify structural performance of the system under service and ultimate loads applied according to AASHTO LFRD and AREMA provisions; (2) Evaluate the structural behavior of anchors connecting the counterforts to base-slab. Highlighted below is a summary of the research study.

Problem Statement

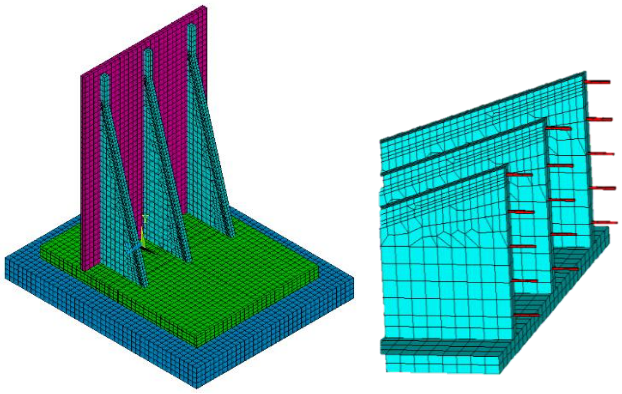
The use of precast concrete in substructure applications for bridges and highways and railway applications is wide spreading. Precast concrete systems provide the advantage of using high performance concrete which is cast off-site and cured in optimum conditions. The products are shipped to the construction site where the components are erected and connected. The current practice is based on cast-in-place construction method which is considered time intensive.

The concrete and structures laboratory at the University of Illinois at Chicago proposed a totally Prefabricated Counterfort Retaining Wall System (TPCCRW) as an innovative retaining wall solution for highway and bridge construction. It was optimized and developed as a response to the growing needs of multiple requirements such as the speed of construction, strength and durability, minimization of railroad-traffic interruption, safety and cost competency. TPCCRW consists of two prefabricated entities: the wall consisting of a face-panel and three counterforts and the base-slab. Headed anchors are used to connect each counterfort to the base-slab and thus enforcing the integrity of the system as one unit. TPCCRW is currently introduced to several construction projects in Illinois such as projects on interstate I94.

This work intends to study the applicability of totally prefabricated precast concrete counterfort retaining wall system (TPCCRW). The finite element model helps identify the structural behavior and the mode of failure of the system which helps in optimizing the system for enhanced efficiency.

Finite Element Analysis

This study is an extension to a previously executed full scale experimental testing. Damage accumulation properties due to cracking and crushing are assigned to concrete. Nonlinear plastic properties were applied to steel reinforcement. The present study reveals that the proposed wall exhibits sufficient rigidity against lateral deflection which was proven by experimental testing. Moreover, it is observed that the failure of TPCCRW is controlled by the ultimate failure of headed anchor located farthest from the face panel.



Finite Element Model of TPCCRW (left) and modeling of extended anchors (right)

The analysis was carried out over several load steps. Since this study is an extension to a previously executed full scale experimental testing, the defined load steps followed the same sequence as in the experimental testing. The sequence starts with applying the self-weight of wall followed by soil backfilling and two feet surcharge load in order to simulate the Service limit state. Then, a nodal load of 200 kip (889.64KN) was applied to imitate the load applied in the field at one third the height of wall (H/3) to carry the system to ultimate load conditions. It was noticed from the Finite element analysis results lection increases with the increase of height. The results were compared to the results obtained from the experimental testing at the mid height and one third the height of the wall and presented in Table 2.

Deflection results from NLFEA compared to experimental results

Limit state	Position	FEA	Experimental data
service limit state (144 Kip)	H	0.21	**0.22**
	H/2	0.1	0.11
	H/3	0.07	0.075
Ultimate limit state (216 kip)	H	0.438	**0.440**
	H/2	0.20	0.22
	H/3	0.13	0.14

It was experimentally difficult to obtain the deflection at the top of the wall in the field. Therefore the actual deflection at the top of the wall was extrapolated using the aid of the finite element analysis after verification with the results at mid-height and one third the height of the wall (shown in bold).

The anchors are the most important factors that affects the integrity of the system. The structural behavior of the anchors in the middle counterfort is examined using finite element analysis. The outermorst anchors (Anchors 1 and 2) exceed the yield limit. Anchor1 (#7 bar) yeilded at 170 kips (756.19 KN) and Anchor 2 (#7 bar) shows yielding strain of 2083 με at 215 kips (956.4 KN) . Generally, the behavior of strain shows a decreasing trend starting from the outermost anchor towards the face of the face-panel. It is expected that anchors with longer moment arm experience higher flexural moment and therefore experience yielding before the anchors with shorter moment arm.

Strain in the anchors results from NLFEA compared to experimental results

Anchor	Bar size	Yield Load (kip)	FEA (mε)	Experimental test results (mε)
1	#7	170	2780	2659
2	#7	215	2083	2204
3	#6	No Yield	1727	1748
4	#6	No Yield	1373	1292
5	#6	No Yield	706	837

Conclusion

- The deflection measured at the mid-height of the wall was found to be around 0.21 in. (5.43 mm). Counterforts added stiffness to the structure by increasing the section at which the bending moment due to the applied load is being resisted. This deflection is incapable of initiating active soil conditions. Therefore, at-rest soil conditions should be used in designing TPCCRW.
- Headed anchors showed excellent performance in maintaining the composite action between the precast wall components at service and ultimate loads. The anchors yield before any failure in the grouted shear pocket. The failure of TPCCRW is controlled by the ultimate failure of headed anchors located farthest from the face panel.
- Cracks initiate in the regions of the internal anchors. These cracks propagate towards the web of the counterforts with the increase of load. The spacing between vertical reinforcements in the web should be reduced to provide arrest mechanism of the cracks and prevent shear failure in the counterforts.

This research was funded by the National University Rail Center (NURail) and the U.S. Department of Transportation – OST. Special thanks are directed to Utility Concrete Products (UCP), LLC. Morris, IL.

Full-Scale modeling of Railroad Bridge using Accelerated Bridge Construction, Precast Concrete Technologies with High Density Polyethylene Crossties.

Ibrahim Lotfy and Mohsen A. Issa.

University of Illinois at Chicago

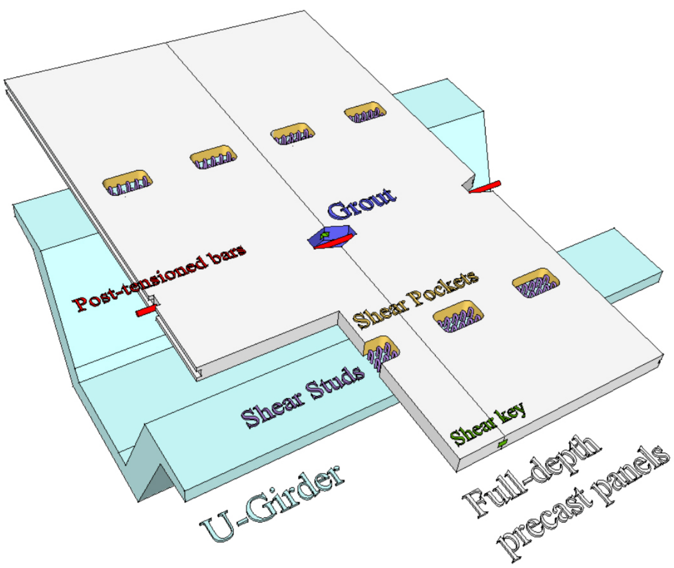
In this brief, two full-scale modeling applications using Accelerated Bridge Construction techniques for railroad elevated structure applications were presented. These two models served as a proof-of-concept for future implementation of High Density Polyethylene crossties in railroad bridges using state of art prefabricated concrete bridge technology and fast construction techniques. These models explored the future scenario of upgrading to High Speed Rail (HSR) in urban setting as well as shared corridors between freight and passenger rail. These models implemented material models and interactions with the fastening system that were calibrated through comprehensive experimental testing. Highlighted below is a summary of this research investigation.

Problem Statement

The major difference between highway and railroad bridges in the US is that the railroad industry is privately owned. Another major difference is that the traffic of highway bridges can be diverted using nearby routes whereas railroad traffic cannot. Moreover, since most of the railroad bridges are privately owned, stringent limitations are placed on traffic delays and closures times, therefore, the focus of railroad bridge projects is economics and safety while constructing under traffic or during short time windows. For this reason, prefabricated simple spans bridges are favored over continuous spans as they can be replaced, one-to-one, between consecutive trains with little interruption to traffic flow. In this study, a proof-of-concept for construction or replacement operations for urban railroad bridges was performed using full-scale modeling. Two prefabricated simple span bridges were considered for both freight and passenger rail using Accelerated Bridge Construction (ABC) techniques. The bridges were considered supporting railroad tracks using HDPE crossties. The full-scale models used material models calibrated through experimental testing.

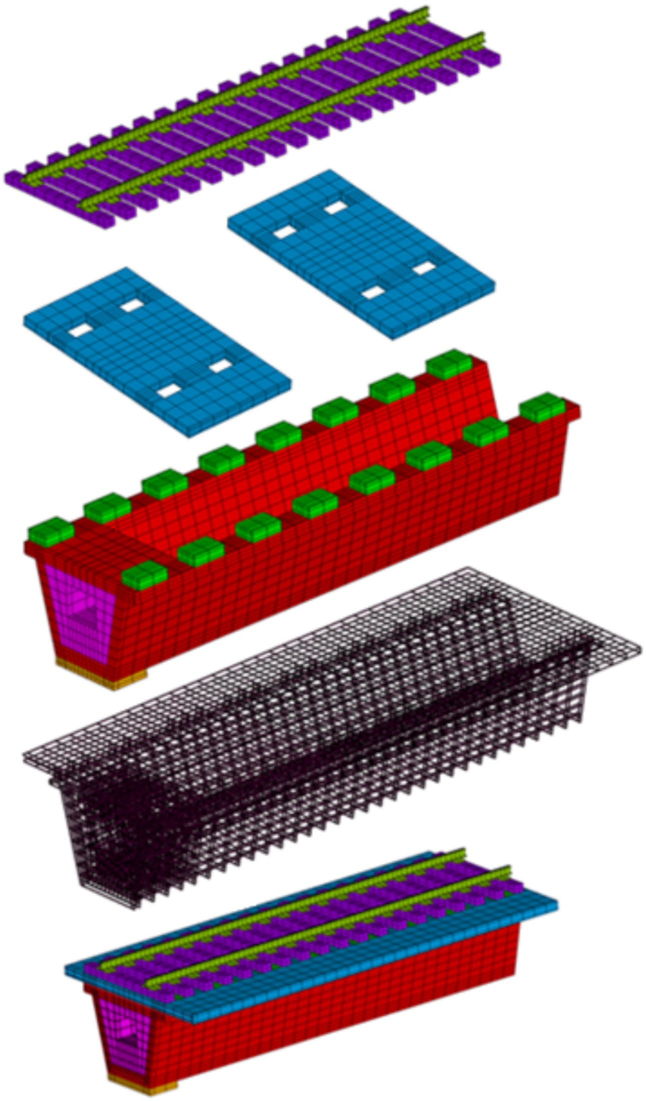
Full-Scale Modeling

The ABC systems explored were pretensioned U-Girders with full-depth precast panel deck system and post-tensioned Box girder system. Both system featured efficient designs that were proven and adopted in the US as well as overseas.

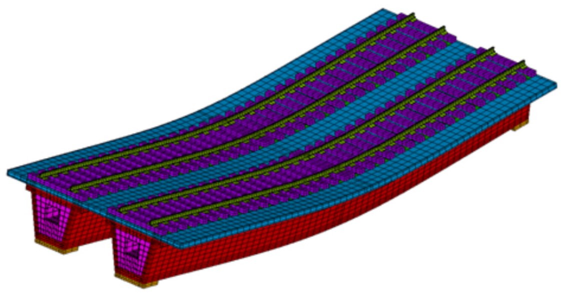


Components of pretensioned thr U-Girders with full-depth precast panel deck system.

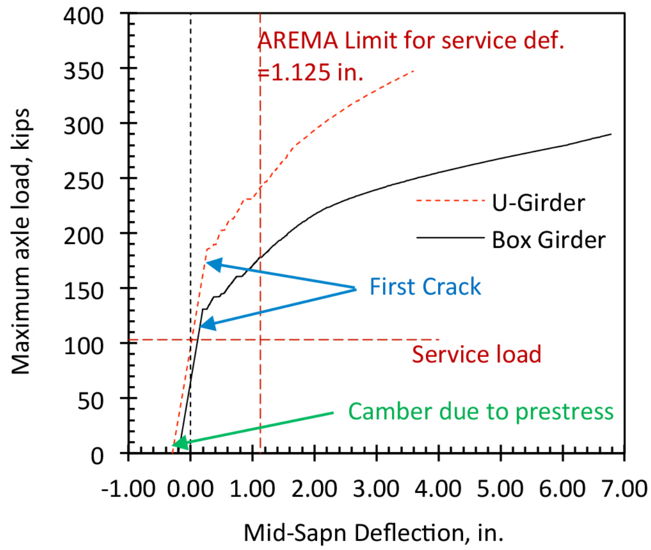
Both systems exhibited favorable performance and fulfilled all the performance criteria recommended by AREMA for freight and the California High Speed Train project for HSR, which highlights the potential of implementing these technologies in future applications.



Model components of the pretensioned U-Girders with full-depth precast panel deck system.



Deflection of the pretensioned U-Girders with full-depth precast panel deck system.



Axle load vs mid-span deflection for both systems.

Conclusion

- Accelerated Bridge Construction plays a major role in construction operations for railroad bridges due to the limited construction windows.
- The material models implemented in the full-scale mode provided accurate representation of the behavior of the full system in actual railroad bridges.
- Both ABC system studied showed favorable performance, which provided a proof-of-concept for future upgrade to HSR in urban setting.
- The pretensioned U-Girder with full-depth precast panels system illustrated great performance showing higher carrying capacity and less deflection than the post-tensioned Box girder system. However, the Box girder system showed a much higher ductility before failure.
- Cracking initiated in the Box girder system significantly before the U-Girder system, at about 70% less load due to the efficiency and multiple girder setup of the cross-section design of the U-Girder system.
- The U-Girder system performed better that expected outperforming the Box girder system. Thus, it is recommended for future investigations and implementation.

This research was funded by the National University Rail Center (NURail) and the U.S. Department of Transportation – OST. The authors would like to acknowledge the contribution of Maen Farhat and Momenur Rahman for his help.

First Name	Last Name	Company	Email
Brian	Abbott	Voestalpine Nortrak	brian.abbott@voestalpine.com
Ahmed	Aboubakr	College of Engineering University of Illinois at Chicago	aabdel23@uic.edu
Daniel	Bailey	College of Engineering University of Illinois at Chicago	dbailey1@uic.edu
Chris	Barkan	University of Illinois at Urbana-Champaign	cbarkan@illinois.edu
Roger	Bittencourt	LabTrans Federal University of Santa Catarina	roger.labtrans@gmail.com
Marcella	Bondie	CUPPA University of Illinois at Chicago	mbondi2@uic.edu
Edward	Bury	Urban Transportation Center University of Illinois at Chicago	ebury@uic.edu
Joel	Carlson	Massachusetts Institute of Technology (MIT)	sjcarlson@gmail.com
Josue	Cesar Bastos	University of Illinois at Urbana-Champaign	cesarba2@illinois.edu
Sam	Chadwick	University of Illinois at Urbana-Champaign	schadwi2@illinois.edu
David	Clarke	University of Tennessee, Knoxville	dclarke@utk.edu
Tyler	Dick	University of Illinois at Urbana-Champaign	ctdick@illinois.edu
Lise	Dirks	Urban Transportation Center University of Illinois at Chicago	ldirks1@uic.edu
Mitra	Dutta	University of Illinois at Chicago	dutta@ece.uic.edu
Riley	Edwards	University of Illinois at Urbana-Champaign	jedward2@illinois.edu
Emma	Ehrenhart	University of Illinois at Urbana-Champaign	trapp3@illinois.edu
Ahmed	El-Ghandour	University of Illinois at Chicago	aelgha2@uic.edu
Maen	Farhat	University of Illinois at Chicago	
Mathew	Fletcher	Hanson Professional Services Inc	mfletcher@hanson-inc.com
Craig	Foster	University of Illinois at Chicago	fosterc@uic.edu
Mike	Franke	Amtrak	fran3624@amtrak.com
LB	Frye	University of Illinois at Urbana-Champaign	lbfrye@illinois.edu
Garrett	Fullerton	University of Illinois at Urbana-Champaign	gfuller2@illinois.edu
Florentina	Gantoi	Sharma & Associates Inc.	mgantoi@sharma-associates.com
Arkaprabha	Ghosh	University of Illinois at Urbana-Champaign	aghosh12@illinois.edu
Robert	Ginsburg	Urban Transportation Center University of Illinois at Chicago	reginsb@uic.edu
Ellen	Gottschling	University of Illinois at Chicago	ellengottschling@gmail.com
Tim	Gress	University of Illinois at Urbana-Champaign	tgress@illinois.edu
Donovan	Holder	University of Illinois at Urbana-Champaign	holder2@illinois.edu
Quentin	Holness	City of Chicago	qholness@gmail.com
Mohsen	Issa	University of Illinois at Chicago	missa@uic.edu
Nikkie	Johnson	Michigan Department of Transportation	JohnsonN15@michigan.gov
Sumanth	Kalluri	Michigan Technological University	kalluri@mtu.edu
Ryan	Kernes	GIC USA	rkernes@gic-usa.com
Asad	Khattak	University of Tennessee, Knoxville	akhattak@utk.edu
Jim	LaBelle	Urban Transportation Center University of Illinois at Chicago	jlabelle@uic.edu
Alexandra	Lakenen	Michigan Technological University	allakene@mtu.edu
Pasi	Lautala	Michigan Technological University	ptlautal@mtu.edu
Samuel	Levy	Massachusetts Institute of Technology (MIT)	samlevy@mit.edu
Po-Yin	Liao	University of Illinois at Urbana-Champaign	pliao8@illinois.edu
Chen-Yu	Lin	University of Illinois at Urbana-Champaign	clin69@illinois.edu
Xiao	Lin	University of Illinois at Urbana-Champaign	xiaolin4@illinois.edu
Jun	Liu	University of Tennessee, Knoxville	jliu34@utk.edu
Ibrahim	Lotfy	University of Illinois at Chicago	ilotfy2@uic.edu
Veronica	Matini	University of South Carolina	Matini@usc.edu
Mike	McHenry	Transportation Technology Center, Inc.	mike_mchenry@aar.com
Jim	McKinney	Rose-Hulman Institute of Technology	james.mckinney@rose-hulman.edu

First Name	Last Name	Company	Email
Michael	McLaughlin	Chicago Transit Authority	MMcLaughlin@transitchicago.com
Lydia	Mercado	US Department of Transportation	lydia.mercado@dot.gov
Peter	Mesha	Wight & Company	pmesha@wightco.com
Hosein	Motamedi	University of Illinois at Chicago	mmotam2@uic.edu
Bosco	Munyaneza	University of Illinois at Urbana-Champaign	munyane2@illinois.edu
David	Nelson	Michigan Technological University	dannelso@mtu.edu
Said	Nour	University of Illinois at Chicago	snour2@uic.edu
James	O'Shea	University of Illinois at Chicago	joshea2@uic.edu
Michael	P Melaniphy	American Public Transportation Association	mmelaniphy@apta.com
Michael	Pagano	University of Illinois at Chicago	mapagano@uic.edu
Sergio 'Satch'	Pecori	Hanson Professional Services Inc.	specori@hanson-inc.com
Nigel	Peters	Canada National Railway (Retired)	njpeters@shaw.ca
Dave	Peterson	University of Wisconsin-Madison	peterson@engr.wisc.edu
Jody	Plahm	Urban Transportation Center University of Illinois at Chicago	jplahm@uic.edu
Hamed	Pouryousef	Michigan Technological University	hpouryou@mtu.edu
Yu	Qian	University of Illinois at Urbana-Champaign	yuqian1@illinois.edu
Dallas	Richards	TranSystems	drrichards@transystems.com
Dimitris	Rizos	University of South Carolina	rizos@engr.sc.edu
Conrad	Ruppert	University of Illinois at Urbana-Champaign	ruppertc@illinois.edu
Rapik	Saat	University of Illinois at Urbana-Champaign	mohdsaat@illinois.edu
Sandeep	Sasidharan	University of Illinois at Chicago	ssasid3@uic.edu
Stephen	Schlickman	Urban Transportation Center University of Illinois at Chicago	sschlick@uic.edu
Ahmed	Shabana	University of Illinois at Chicago	shabana@uic.edu
Vinaya 'Vinny'	Sharma	Sharma & Associates	vsharma@sharma-associates.com
Aiman	Shibli	University of Illinois at Chicago	ashibli2@uic.edu
Mei-Cheng	Shih	University of Illinois at Urbana-Champaign	mshih2@illinois.edu
Sostenes	Silva Pereira	Rose-Hulman Institute of Technology	sostenespereira@hotmail.com
Jordan	Snow	Urban Transportation Center University of Illinois at Chicago	jsnow7@uic.edu
Reg	Souleyrette	University of Kentucky	souleyrette@uky.edu
Leonan	Stocco Braido	University of Illinois at Chicago	leonansb@hotmail.com
Michael	Stroscio	University of Illinois at Chicago	stroscio@uic.edu
Joseph	Sussman	Massachusetts Institute of Technology (MIT)	sussman@mit.edu
Ahmadreza	Talebian	University of Illinois at Chicago	ataleb2@uic.edu
Haichuan	Tang	University of Illinois at Urbana-Champaign	hctang@illinois.edu
Denver	Tolliver	Upper Great Plains Transportation Institute - NDSU	denver.tolliver@ndsu.edu
Brandon	Van Dyk	Vossloh Fastening Systems America Corporation	brandon.vandyk@vossloh-usa.com
Robert	VanderClute	FirstRail International, LLC	rcvorb@outlook.com
Brandon	Wang	University of Illinois at Urbana-Champaign	zwang137@illinois.edu
Teng	Wang	University of Kentucky	wangtengyilang@uky.edu
Douglas	Whitley	Supply Chain Innovation Network of Chicago (SINC)	dwhitley14@gmail.com
Stephen	Wilk	University of Illinois at Urbana-Champaign	swilk2@illinois.edu
Meng	Zhang	University of Tennessee, Knoxville	mzhang27@vols.utk.edu
Kaijun	Zhu	University of Illinois at Urbana-Champaign	kzhu12@illinois.edu
Bo	Zou	University of Illinois at Chicago	bzou@uic.edu

U.S Department of Transportation

Office of the Assistant Secretary for Research and Technology

NURail Center

National University Rail (NURail) Center
University of Illinois at Urbana-Champaign
1239B Newmark Civil Engineering Laboratory, MC-250
205 N. Mathews Avenue
Urbana, IL 61801
217-244-4999 (phone)
217-333-9464 (fax)
NURail-Center@illinois.edu

Visit our website: *http://www.nurailcenter.org*

ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN · UIC UNIVERSITY OF ILLINOIS AT CHICAGO · Massachusetts Institute of Technology · Michigan Tech · UK UNIVERSITY OF KENTUCKY · THE UNIVERSITY of TENNESSEE KNOXVILLE · ROSE-HULMAN INSTITUTE OF TECHNOLOGY