Working on the Highway:
The Road to More Sustainable and Resilient Pavements through Collaborations in the UK

My motivation for this research

Roads. Societies around the globe rely on a functioning network of roads to transport people and goods in an efficient manner. A functioning road network requires pavements that can withstand required traffic and environmental loadings to provide smooth, safe, effective passage so we're not "stuck in the mud." The US invests over $40 billion each year (www.artba.org/about/transportation-faqs/#7) and the UK plans to invest over £12 billion in 2014 (HM Treasury, 2013) to maintain and rehabilitate roads and bridges; this indicates the importance of designing and building longer lasting pavements that are cost effective. The work I propose to conduct with Fulbright support will examine two areas of pavement engineering that are complementary to achieving more resilient and sustainable pavements: 1) the use of recycled materials in pavements, and 2) the impact of changing climate on the design, maintenance, and performance of pavement systems. Implementation of this work will ultimately save taxpayer money and provide a more reliable roadway system to the travelling public.

There's nothing quite like the feeling of driving on a smooth new pavement. Unfortunately, pavements degrade over time due to the action of traffic and exposure to weather. If a pavement is not properly designed, constructed, or maintained over time, eventually it will fail. Failure of a pavement system can take different forms that range from catastrophic washouts due to flooding to material failures in the pavement layers that create unsafe or very rough driving conditions (see Figure 1 below). Failed pavements cause more wear and tear on vehicles, increase fuel consumption, increase the risk of accidents, and can disrupt the whole road system or even completely isolate communities.

Figure 1. Examples of pavement failure (l to r): Pavement buckling from high temperatures; fatigue cracking and rutting on an asphalt concrete pavement; road closure due to pavement inundation during a flood event; and pavement washout from a flood event.

Pavements are engineered systems that consist of multiple layers of materials that spread out the weight of vehicles so that many vehicles can travel safely at high speeds without sinking into the ground (similar to how you can more easily cross a muddy area by putting down a board to walk on). More than 95% of pavements in the US and UK use asphalt concrete as a surface material. Asphalt concrete is composed of aggregate (rocks and sand) held together by asphalt cement (black sticky glue). The majority of asphalt cements used in paving applications are produced through the refinement of crude oil; thus the cost of asphalt cement, and by extension, asphalt concrete, is subject to dramatic increases coinciding with rising crude oil prices. Recycling of old asphalt concrete pavements that contain quality asphalt and aggregate is an

effective practice that has been employed for decades, and can create considerable savings of costs and resources. However, the asphalt cement in the recycled asphalt pavement (RAP) has different properties than virgin asphalt cement due to the exposure to weather. If not properly designed, new asphalt concrete that includes RAP can be brittle and therefore susceptible to early failure. Researchers have identified many factors that contribute to the success of recycled materials, but these factors are not yet fully understood (see references in Bibliography). The focus of my research in this area will be to evaluate several of these factors.

The materials that are used in pavement structures are sensitive to changes in temperature and moisture and therefore must be designed for a specific climate. Typically, this is done using historic climate data, which assumes that the past climate is a good indicator of future climate conditions expected during the design life of the pavement. However, we know that the climate around the globe is changing. Expected changes that include increases in mean temperature, more frequent extreme heat events, heavy precipitation events, rising sea level, and stronger hurricanes have already been observed (Walsh et al., 2014). Changes in temperature and precipitation can create significant changes in the strength of the pavement that may cause the pavement to fail much earlier than expected (Meagher et al., 2012). For pavements to be designed to withstand future climate conditions, engineers need to have an understanding of the assumptions and uncertainties associated with future climate projections and climate scientists need to have an understanding of the type of information that engineers need. The focus of my research in this area will be to facilitate and expand this understanding.

My qualifications to do this research

The overall goal of my research is better performing roads that are sustainable and can handle future traffic and environmental loadings. My primary research focus is the characterization and evaluation of asphalt concrete mixtures containing recycled materials, and in the last several years, I have begun developing collaborative, interdisciplinary research around climate change and infrastructure issues. These areas will be the focus of my future research and hence, my Fulbright plan contains components of both.

Cracking performance is the major concern with asphalt mixtures that contain recycled materials. In my work, I apply a theoretically-based approach (called the S-VECD approach) to gain a better understanding of how the inclusion of brittle RAP materials impacts the cracking performance of asphalt concrete mixtures. My work to date has shown that the properties of the individual source materials (virgin and recycled) are important as well as the conditions under which the two materials are mixed (Mensching et al., 2014, Bennert et al., 2014, Daniel et al., 2013, Mogawer et al., 2012). Therefore, my most recent work has focused on the evaluation of mixtures produced in the field and field performance over time through funding at the state, regional, and national level. I have worked extensively with state transportation agencies on projects evaluating field performance (Barry et al., 2014, Anderson and Daniel, 2013), aging of RAP mixtures (Tarbox and Daniel, 2012), and, currently, evaluation of specifications. One of my graduate students, David Mensching, is working to develop an indicator parameter for cracking performance; results of that work will be applied in my Fulbright research as well.

On the climate and infrastructure side, I am the co-principal investigator of the Infrastructure and Climate Network (ICNet, theicnet.org), funded through the National Science Foundation Research Coordination Network–Science, Engineering and Education for Sustainability program. ICNet is a collaborative research network that provides a voluntary

forum for universities, states, and federal partners to identify, coordinate, and collaborate on regional approaches to support actionable use of climate information in the Northeast US region's transportation infrastructure. We have been very successful in bringing together climate scientists, engineers, and stakeholders by employing social science methods to better understand each other's disciplines, capacity, and challenges, and to identify specific knowledge gaps that currently challenge the inclusion of future climates in engineering practice (Daniel et al., 2014). Research projects related to ICNet have included methodologies to include future climate data in infrastructure design (Meagher et al, 2014) and application of a system dynamics approach to evaluate vulnerability of pavements to flooding (Mallick et al, 2014). I am also principal investigator for a Federal Highway Administration project, *Assessment of Flooded Pavements*, and a regional project to evaluate the impact of temperature and moisture on the properties of asphalt pavement base courses containing recycled materials.

Why Nottingham, UK?

There are both professional and personal reasons why I've chosen Nottingham for my proposed activities. First, the Nottingham Transportation Engineering Centre (NTEC) has a very highly regarded research group in pavement engineering (including both materials testing and impact of climate) and a laboratory equipped to allow for the research that I am proposing to conduct. I have a direct connection with Prof. Gordon Airey and several other researchers at the NTEC (see letter of invitation from Prof. Andrews) and I am confident I will be able to strengthen and expand my connections during my visit. The NTEC has two research projects that will be ongoing during my proposed Fulbright tenure that my proposed work will augment by providing additional testing and analysis. The first is the AllBack2Pave (http://allback2pave.fehrl.org/) €450,000 project that focuses on plant produced mixtures containing high levels of recycled materials. This is a collaborative effort with NTEC, Dresden University of Technology (TUD) in Germany and the University of Palermo (UNIPA) in Italy. Materials from this study will be collected for my testing at NTEC; my testing will augment that already planned during the project. I will take the opportunity to visit TUD and UNIPA as part of the project to further expand my international connections and possible future collaborations. The second research project (SUP&R ITN) is a 4-year, €4.1 million Marie Curie Initial Training Network (http://superitn.eu/wp/) that is a collaboration with a range of European academic and industrial partners to train researchers in Sustainable Pavements and Railways through multidisciplinary international projects. The researchers supported by this project will be working in both areas of my proposed research and will provide complementary experience and opportunities to collaborate and learn from each other. I also plan to take advantage of the proximity to research meetings and conferences in Europe that I have not attended regularly in the past because of the significant travel distance from the US. This also will help me to expand my international connections and collaborations.

Personally, Nottingham will be an invaluable experience for our whole family. We have three daughters who will be ages 11, 8, and 5 during the proposed trip and we are going to take full advantage of the cultural experience with them. Our plan is to arrive in time for the girls to start the school year so that they can be immersed in the culture and form their own friendships while maintaining a familiar schedule. We are an active, outdoors family and so would very much enjoy the membership to the National Trust/Royal Oak Foundation (the girls will love the secret places!) and the ability to visit and explore old structures, gardens, and natural areas across the UK that are very different from the US. The whole family will enjoy visiting London and

attending cultural events through the English Speaking Union. And finally, we live in Nottingham, NH, so it will just plain be fun to go from one Nottingham to another. We hope for the whole family to build a connection between the two Nottinghams that can continue once we return home.

Proposed Research Plan

The research that I will conduct with Fulbright support will include a combination of experimental work in the laboratory and developing collaborations with climate scientists and pavement engineers. The specific plan for each of these areas has been developed in collaboration with my contacts at NTEC to provide significant benefits for the researchers and students in the UK as well as to further my own research and overall understanding of the materials and systems and provide the basis for future collaborative research, partnerships, and student exchange.

Evaluation of Recycled Mixtures

Testing will be conducted on at least two different sets of plant-produced mixtures from the AllBack2Pave project. Sets of mixtures will be selected to include two different virgin binders and two different RAP levels (low and high). The intent with the selection of these mixtures is to determine if similar trends exist with European mixtures that have been observed with US materials. This will allow me to gain a better understanding of the interactions that occur between virgin and RAP materials. Dynamic modulus and uniaxial tensile fatigue testing will be done on at least three replicate specimens. The testing will be accomplished with the (volunteer) help of graduate students working at the NTEC on complementary projects as well as researchers supported under the SUP&R ITN project. Analysis will be conducted to evaluate the susceptibility of the mixtures to cracking using the S-VECD approach and the cracking parameter being developed at UNH. I will also work with students to conduct similar analysis on the test data from their projects and with test data from past projects. I anticipate that the testing will take approximately 3 months' time, leaving 3.5 months for analysis.

Climate and Pavements

The research efforts in this area will be conducted simultaneously with the experimental program task. I will work first with the faculty at NTEC that have been conducting research around climate issues and pavements to understand the approaches that they have been using and the connections that they have made. This will include the climate model output that is used, downscaling methods, etc. – essentially learning how they have generated the future climate used in their analyses. I also will start making connections with climate scientists at Nottingham and across the UK to get an understanding of the work that they are doing. As part of this application preparation and ongoing ICNet activies, I have made initial connections with climate researchers in Newcastle (Richard Dawson, Alistair Ford, Hayley Fowler) that work at the interface between infrastructure modelling, engineering, and climate change. As I identify the appropriate engineers and researchers, I will invite them to participate in ICNet as international collaborators. I will apply the lessons learned and techniques used successfully in ICNet to facilitate interactions, learn what they've been doing to expand how I'm thinking about the problem and spur new ideas and approaches as well as identifying research needs and establishing international collaborations. This is a unique opportunity to bring the international groups together because I will have the time and proximity to actually get to know the individuals and work with them in person, which we have found to be essential to the success of

the ICNet activities to date. This will work to expand ICNet – growing research capacity to help to answer infrastructure and climate questions on regional scales and develop approaches that can be transferrable to different geographical regions as well as different sectors. In the process, I will be exposed to different approaches to pavement design and maintenance and have the opportunity to bring new knowledge and ideas back to UNH.

Benefits and outcomes of my Fulbright research and experience

This proposed Fulbright project will have significant benefits to me professionally and personally and also will provide benefits for other researchers at UNH and University of Nottingham. Both areas of my research are complementary to work that is ongoing at NTEC. The materials testing I plan to conduct will augment testing that is already planned for the AllBack2Pave project as well as providing a unique set of data to evaluate my hypotheses based on work conducted on US mixtures. I also will be able to bring the S-VECD analysis approach to the research team at NTEC, thus expanding their capabilities. I will be able to establish research connections across UK and Europe that would otherwise be very unlikely to occur and I anticipate that these will lead to new collaborations and international partnerships, which can benefit the research and students alike. This directly contributes to UNH's strategic internationalization effort by increasing opportunities for international student exchange. I will also strengthen existing relationships. I will be able to bring the experience I have from ICNet to the UK and expand the network to more effectively address some of these problems on a global scale. Since the intersection of infrastructure and climate is a relatively new area of research, I anticipate making many new connections that would not be possible without physically being in the UK for an extended period of time. While I am abroad, I will meeting regularly with my UNH graduate students via web conferencing and will involve my colleagues and students at NTEC (and elsewhere) so that other connections can be initiated. I anticipate that at least one peer reviewed publication in each research area will be produced along with presentations at international conferences and specific plans for future research projects. Finally, the experience will be invaluable for my family. We welcome the opportunity for our daughters to be immersed in a different culture for a significant amount of time and for us all to be able to explore different areas of the UK and gain a deeper appreciation for, and connection to, the country and its people.

References

HM Treasury and Infrastructure UK. Investing in Britain´s future. 2013, ISBN 978-0-10-186692-7.

Walsh, J., D. et al. 2014: Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program.

All other references are listed in my CV