House Committee on Science, Space and Technology
Subcommittee on Research and Technology

Hearing: Composite Materials – Strengthening Infrastructure Development

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Chairman Comstock, Vice Chairman Marshall, Ranking Member Lipinski and other committee members, I appreciate the invitation to testify before the subcommittee. I am a professor of civil and environmental engineering at the University of Illinois. I serve as director of a 23-year old research center based at the University of Illinois called the Center of Excellence for Airport Technology. I also am the current President of the American Concrete Institute, an organization of 20,000 members who participate in over 400 technical and educational committees and sub-committees, and produce the codes, standards, and guides that govern construction of reinforced concrete in the US and around the world.

Today we are here to discuss fiber reinforced polymer (FRP) composite products for infrastructure applications. I understand that this hearing was motivated by a workshop held at NIST in 2017 that generated a roadmap document addressing barriers to adoption.[1]

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[1] NIST Special Publication 1218, "Road Mapping Workshop Report on Overcoming Barriers to Adoption of Composites in Sustainable Infrastructure," December 2017, available at: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1218.pdf

Historical context

FRP composites have been used in structural engineering at some level for 50 years for new construction and repair applications. FRP products have found a place as an alternative to steel reinforcing bars in concrete and in repair, rehabilitation, and retrofitting. FRP products are often used as a strategy to overcome concern about steel corrosion. The attractive properties of FRP have motivated significant investment in research – particularly in the 1980s and 1990s – and have led to many funded demonstration projects. Today, FRP is considered to be a well-understood high-strength, low-weight, and durable material. FRP products are fabricated in factory settings and are manufactured with a high level of quality and consistent performance. Thousands of research studies on FRP have been published. A comprehensive textbook on FRP structural applications lists numerous review papers on developments in the field.[2] Design guides for use of FRP bars in reinforced concrete have been developed by ACI Committee 440.[3]

Despite these attractive attributes and a reasonably successful track record in field demonstration, we do not see broad and significant adoption of FRP in construction today. The NIST workshop brought together about 60 specialists from NIST staff and industry to contemplate the barriers that exist in the marketplace and suggest actions that might diminish those barriers.

The construction industry is dominated by venerable design paradigms

Commercial construction of buildings and bridges have generally used either of two dominant design paradigms: reinforced concrete or structural steel. Concrete and steel are traditional material systems that have been proven successful over the years. Sizeable industries have risen to build our nation's infrastructure, and these two competing material systems seem to have thrived in a competitive marketplace. These are old and venerable design paradigms. The

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[2] Lawrence C. Bank, *Composites for Construction: Structural Design with FRP Materials.* John Wiley & Sons, Inc. ISBN: 978-0-471-68126-7, 2006.

[3] Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars, ACI 440.1R-06, American Concrete Institute, Farmington Hills, MI, 2006.

first structural steel building specification by the American Institute of Steel Construction (AISC) was published in 1923 and the first reinforced concrete building code by the American Concrete Institute (ACI) was published in 1910. In contrast, the first textbook on design with FRP for civil structural applications was published in 2006.

The dominant design paradigms are not static. Large organizations work tirelessly to refine concrete and steel design provisions. For example, the American Concrete Institute has 20,000 members representing the construction industry, design profession, and academia. Although concrete is an old material, the human capital working on its behalf assures that today's concrete is not your father's concrete. Concrete of today has evolved to a high level of performance, constructability and durability. Design tools today are increasingly able to handle complexity, and it seem important that we encourage harmonization of material systems so these two silos – concrete and steel – have effective cross-talk and openness to newer materials such as FRP. Over time – certainly not a short time – the advances have included provision for FRP rebar. ACI Committee 440 "FRP Reinforcement" has developed design guidance and ASTM D7957 "Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement" codifies one of the leading product categories for use of FRP.

All this is to say that the prevailing structural design codes for concrete and steel structures are strong in the marketplace, and represent some level of resistance to FRP products, particularly for designs that are 100% FRP rather than combinations of FRP/concrete or FRP/steel concepts.

The nature of construction industry is conservative

The construction industry is a conservative industry governed by low risk tolerance and "low bid" contracting. It is rightly conservative because life safety responsibilities are paramount, and no engineer is going to release an unproven or risky design. Furthermore, construction contracts are most often awarded in competitive processes that reward low initial cost. Everyone recognizes that low initial cost may not deliver low life cycle cost, but the tools to analyze life cycle cost are still emerging. This area continues to be a challenge, and until we disband low initial cost as criteria, alternative materials with superior durability and service life will face a barrier to adoption.

Superior durability is not always enough to drive adoption. Owners appreciate durable solutions, but the tools to accurately predict service life are not commonly integrated into specifications. It is difficult to describe the mechanisms that control durability in mathematical models. The prevailing models for service life of concrete rely on transport of chlorides as a factor in initiation of corrosion, but may not consider the many pathways for chloride ingress. Furthermore, superior durability may not be very important to owners in the private sector. Functional obsolescence truncates the service life of buildings as often as poor durability. Even if the building has a long life, the time horizon for ownership and financial investment may be relatively short, leading to a de-valuation of long-term durability.

If decision-makers have low risk tolerance and short time horizons, they will not assert a strong "pull" of the FRP technology into practice.

Adoption should be driven by authentic advantages of FRP

As discussed above, FRP offers well-known advantages of being durable and lightweight. FRP is marketed to compete in a world of traditional rectilinear beams and columns, but FRP is also amenable to take on creative organic shapes. Even with FRP rebar, the expectation is that FRP is adopted as a simple replacement for lengths of straight steel bar. Shell structures are relatively simple to accomplish using FRP material systems – if only architects would require them. While there are demonstrations of such structures, organic flowing shell structural elements are relatively uncommon in commercial buildings and bridges.

FRP products have dominated in certain applications. FRP transformed the aircraft and marine industries in a fairly short time period. Attributes of low weight, complex curvature, and excellence durability worked in the favor of FRP. More recently, FRP has come to dominate the market for wind turbine blades and cooling tower structures. All of these examples exploit the advantage FRP offers for creating complex shapes.

The adoption of FRP needs to be based on authentic advantages. Durability, low weight, organic form, flexibility and high strain capacity are among those competitive advantages. Even cost may someday be seen as an advantage if the price of steel rises and maturity of the FRP industry leads to reduced costs.

Engineering education has not functioned as a "change agent"

Established professional disciplines are defined by a canon of technical knowledge that is taught to students entering the profession. The canon evolves slowly, and is perhaps seen as changing in a sluggish response to the more rapid changes in industry. New knowledge arising from research does not necessarily find its way into the canon without strong demonstration of need from industry. Across the 220 civil engineering undergraduate programs in the US, structural steel and reinforced concrete are emphasized because of their common use in industry; even wood and masonry design receive scant attention. In contrast, FRP is rarely covered in the civil engineer's education, especially in a four-year undergraduate program. Students who pursue a masters degree in structures tend to add more coursework on complex steel and concrete behavior. Courses dedicated to FRP and structural repair and rehabilitation are practically nonexistent. This effectively cuts off the opportunity to motivate industry change with new generations. Furthermore, young practitioners are mentored by senior, professionally licensed structural engineers, and so there is little opportunity to challenge the dominant design paradigms. Thus in many ways, engineering education follows rather than leads adoption of innovation In the construction industry, and the educational challenge must be seen as having a professional life-long learning component to impact senior engineers in practice.

Civil engineering education is trending toward recognition of the Masters degree as a "first professional degree." Other professions such as medicine, law or accounting require training beyond the bachelor’s degree, and civil engineering – especially structural engineering – is approaching that expectation. In a structures MS program, additional opportunity is available for technical specialization, and it would seem that universities could choose to develop stronger offerings for design of FRP structural systems. I think this would happen if a need from industry were to drive it. Relatively few civil engineering programs have yet developed FRP courses or other courses that harmonize concrete, steel, masonry, and wood. Design of these structural systems are most commonly taught as independent from one another. ACI with its treatment of FRP rebar for reinforcement in concrete and connections between structural steel and reinforced concrete members stands as an exception.

What is role of Federal Government?

The construction industry is conservative, highly valuing safety, low risk, and low cost. These are further entrenched by an industry that is overly influenced by short term factors. In contrast, disruptive innovation can be more attractive when a longer term perspective is taken. We can’t expect a highly fractured industry, dominated by small companies, to discount risk, fund research, and develop education initiatives for the long game.

The federal government can help the construction industry adopt a long term perspective. It can ensure a sustained level of research funding that creates new ideas and fosters faculty commitment to FRP curriculum and harmonization of materials in structural systems.

There are other examples of innovative materials that have taken a long time to gain traction in the construction industry. Fiber reinforced concrete (FRC) and self consolidating concrete (SCC) are two such developments that are trending toward wider adoption. Documents produced by ACI Committee 544 FRC and Committee 237 SCC are strong contributions that provide guidance for practitioners to use these newer materials.

The NIST roadmap (Figure 1) has attractive elements. In particular, I am drawn to one of the recommendations related to the “Design Data Clearinghouse” barrier. The idea expressed in the report was to charge NIST as a neutral party to compile durability data and define limits using codes and standards. The report remarked that academia could be used to develop measurement methods and models. As an example of how codes and standards can spur adoption, the 2017 release of ASTM D7957 for FRP rebar has already had impact on the ability for that product to be specified and designed. An industry representative shared with me a positive outlook, and suggested that there has been an upswing in bridge deck projects in recent months.

A second element of Figure 1 that I endorse is the barrier entitled “Education and Training” and the need to develop curriculum. Given the large body of existing research, it is reasonable that federal funding might target that gap as a way to encourage civil engineering programs to bolster their MS course offerings in design of FRP or “harmonized materials systems.”

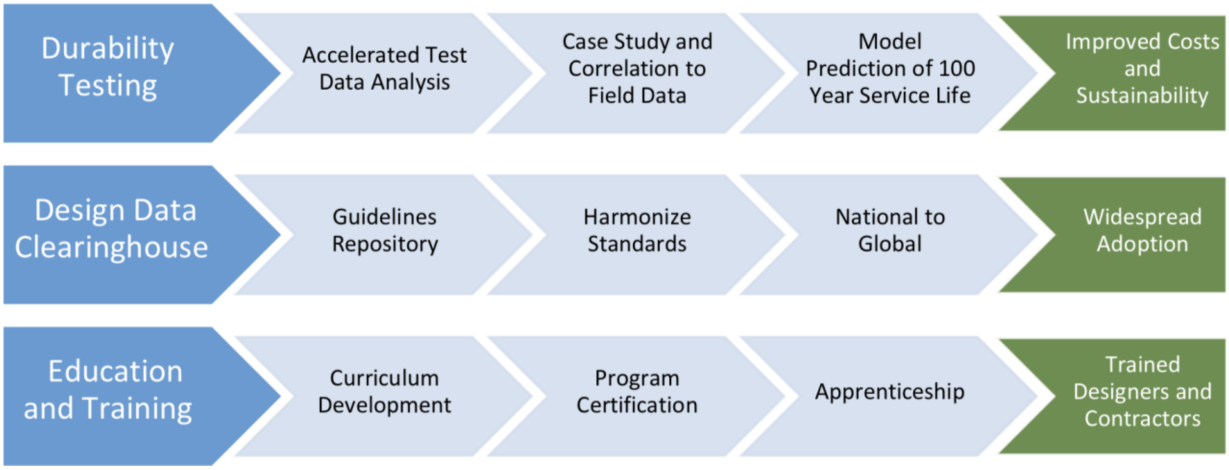

Figure 1. Preliminary Roadmap designed during the NIST workshop in 2017. This roadmap captures the nine basic efforts (center-section) that need to be completed to overcome the top three barriers (left-side) and achieve the three critical outcomes (right-side). [From [1], 2017]

Another proven mechanism available to the federal government is funding research centers that encourage effective partnerships between academia and industry. My own experience with CEAT has persuaded me that large infrastructure programs can benefit from partnerships with universities. Since 2005, CEAT has been funded by O’Hare International Airport and the Chicago Department of Aviation. Every year, we engage with O’Hare engineers to identify their most pressing questions related to the now-completed $8.0B O'Hare Modernization Program and the just-announced new $8.5B makeover program. We select our research projects to "inform the decision making process," reduce risks, and save money. A university research center – similar to DOT University Transportation Centers (UTC) or Engineering Research Centers (ERC) can be designed to promote FRP adoption through strong partnerships with longer term infrastructure programs.

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David A. Lange is Professor of Civil Engineering at the University of Illinois at Urbana-Champaign. His research area is concrete materials, microstructure-property relationships, airport pavements, concrete rail crosstie durability, foamed cement materials, and recycled concrete. He serves as Director of the Center of Excellence for Airport Technology, a research center sponsored by the O'Hare Modernization Program and the Federal Aviation Administration. Lange has published over 100 technical papers and reports, including over 90 refereed journal papers. He is a Fellow of the American Ceramic Society. He is also a Fellow of the American Concrete Institute and winner of its Wason Medal in 2003 and 2018. He serves as President of ACI, member of the ACI Board of Direction, past chair of the ACI Technical Activities Committee, and has served ACI in many other roles.

Education

Ph.D., Civil Engineering, Northwestern University, 1991
M.B.A., Wichita State University, 1984
B.S., Civil Engineering, Valparaiso University, 1981

Professional Experience

2005-present	Professor, Department of Civil and Environmental Engineering, UIUC
2004-present	Director, Center of Excellence for Airport Technology
2004-2010	Associate Head, Department of Civil and Environmental Engineering, UIUC
1999-2005	Associate Professor, University of Illinois at Urbana–Champaign
2003-2004	Associate Director of the NSF Center for Advanced Cement-Based Materials
1993-1999	Assistant Professor, University of Illinois at Urbana–Champaign
1992-1993	Visiting Assistant Professor, University of Illinois at Urbana–Champaign
1987-1992	Graduate researcher, Northwestern University, Evanston, IL
1981-1987	Engineer, Boeing Military Airplane Co., Wichita, Kansas

Professional Licensure

Professional Engineer, State of Illinois, License # 062-049600

Selected honors

American Concrete Institute, Wason Medal for Most Meritorious Paper, 2018
Distinguished Professor, University of Jinan, China, 2017
J. William Fulbright Scholar Award, 2013
College of Engineering Teaching Excellence Award, 2013
Stanley Pierce Award for faculty-student relations, 2011
Chi Epsilon, Honorary Member, 2010
UIUC iFoundry Fellow, 2008
ASCE Glen L. Martin Best Paper Award with co-authors J. Evans, D. Lynch, 2008
American Ceramic Society Fellow, 2005
Xerox Award for Faculty Research, 2004
American Concrete Institute, Wason Medal for Most Meritorious Paper, 2003
American Concrete Institute Fellow, 2002
Narbey Khachaturian Faculty Scholar, 1998
NSF Career Award, 1996

Ten Recent Journal Publications

1. J. Xiao, C. Sun, D.A. Lange, "Effect of joint interface conditions on shear transfer behavior of recycled aggregate concrete," Construction and Building Materials 105 pp 343355, 2016.
2. Y Qian, H. Wolf, J.R. Edwards, M. Dersch, D.A. Lange, "Temperature-Induced Curl of Prestressed Concrete Monoblock Railroad Crossties," Construction and Building Materials, Construction and Building Materials, 115, pp 319326, 2016.
3. I. You, J. Choi, G. Zi, D.A. Lange, "Pozzolanic reaction of waste glass sludge incorporating precipitation additives," Computers and Concrete, Vol. 17, No. 2, (DOI: 10.12989.cac.2016.17.2.000), 2016.
4. N.J. Gardner; Keller, L.; Khayat, K.H.; Lange, D.A.; and Ahmed R. Omran, Field Measurements of SCC Lateral PressureToronto 2014, Concrete International, Vol 38, No. 6. Pp 42-50, 2016.
5. S. Zhao, E. Van Dam, D.A. Lange, W. Sun, "Abrasion resistance and nano-scratch behavior of an ultra-high performance concrete," ASCE J. Mat. Civil Eng.,[DOI: 10.1061/(ASCE)MT.1943-5533.0001744] 29(2): 04016212, 2017.
6. Y. Song, R. Zou, D. Castaneda, K.A. Riding, and D.A. Lange, "Advances in Measuring Air-Void Parameters in Hardened Concrete Using a Flatbed Scanner," ASTM J. Testing and Evaluation, Vol. 45, No. 5, 2017, pp. 17131725, http://dx.doi.org/10.1520/JTE20150424. ISSN 0090-3973.
7. J. Kim, G. Zi, D.A. Lange, "Measurement of Water Absorption of Very Fine Particles using Electrical Resistivity," ACI Mat. J., DOI: 10.14359/51700994, Vol 114, 6, 2017.
8. A. Shurpali, J.R. Edwards, R. Kernes, D.A. Lange, C. Barkan, "Improving the Abrasion Resistance of Concrete to Mitigate Concrete Crosstie Rail Seat Deterioration (RSD)," J. Materials Performance and Characterization (ASTM), doi:10.1520/MPC20170051, Vol. 6, No. 1, 2017.
9. C. Sun, D.A. Lange, J. Xiao, and T. Ding, "Contact behavior between cracked surfaces of recycled aggregate concrete," J. Construction and Building Materials, accepted 2017. (CONBUILDMAT-D-17-01764R1)
10. D. Casteneda, K. Riding, D.A. Lange, "Measurement and Validation of Freezing Internal Temperature of Concrete Crossties at the Rail Seat," J. Mat. Civil Eng. (ASCE), accepted 2017.