Congressional Testimony

21st Century Communities: Climate Change, Resilience, and Reinsurance

Testimony before
The Committee on Banking, Housing, and Urban Affairs
The United States Senate

July 20, 2021

Abdollah Shafieezadeh, Ph.D.
Lichtenstein Associate Professor
Department of Civil, Environmental and Geodetic Engineering
The Ohio State University

Chairman Brown, Ranking Member Toomey, and Members of the Committee on Banking, Housing, and Urban Affairs,

My name is Abdollah Shafieezadeh. I am the Lichtenstein Associate Professor of Civil, Environmental and Geodetic Engineering at The Ohio State University (OSU). I am also the director of Risk Assessment and Management of Structural and Infrastructure Systems lab at OSU. It is my great honor to share with the committee my insights on the state of the nation's critical infrastructure, current and future risks, especially those that are imparted by climate and weather hazards, and some of the ways we can pursue to improve the resilience of our infrastructure and communities.

The Significance of the Nation's Infrastructure

The daily life of Americans, the long-term economic prosperity of the nation and the national security of the United States depend on the continued functioning of a large set of infrastructure systems in the country. These systems that form the backbone of our society are complex in terms of their scale, and system operations and interdependencies under normal conditions and when challenged by the stresses of the environment. Attending these risks in a cost-effective manner requires a strategic vision that includes long-term planning with a flexibility included to adapt to uncertain conditions of the future.

The physical and operational scales of our infrastructure are significantly large. As an example, the power grid in the U.S., is widely considered the most complex engineered system in the world. It includes over 8,000 power plants, 600,000 miles of high and extra high voltage transmission lines and millions of miles of distribution lines[1]. At every instant in time, this system balances electricity supply and demand, and delivers power from distant generation units to energy consumers through a web of transmission and distribution networks. We have over 4 million miles of public roadways and over 600,000 bridges across the United States. Together,

[1] U.S. DOE, "Dynamic Line Rating Report to Congress," June 2019, https://www.energy.gov/sites/default/files/2021/03/f83/DLR%20Report%20-%20June%202019%20final%20-%20FOR%20PUBLIC%20USE.pdf.

they facilitated 3.2 trillion vehicle miles traveled in 2019[2]. More than 16,000 wastewater treatment plants in the country and a web of tens to tens of thousands of miles of pipelines under small communities to large cities collect and process over 60 billion gallons of wastewater every day[2]. Similarly, we have other vast interconnected and interdependent systems of telecommunication, water, dam and levees, healthcare and emergency services, among many others, that provide immediate and long-term critical services to the society[3].

Challenges Facing Our Critical Infrastructure

The current state of our critical infrastructure, however, is not good, and for many systems, the state is far from good. According to a nationwide assessment of the state of our critical infrastructure across the nation by the American Society of Civil Engineers (ASCE), which I am a member of, America's infrastructure scores C-[2,4]. A grade of C means that the infrastructure state is mediocre and requires attention, and a grade of D means that the infrastructure is poor and at risk[2].

Our infrastructure, for a long time, has been a source of pride for the nation. The vast power grid, highway systems, water and wastewater networks, among our other infrastructure systems have changed the way of life, created jobs and provided many opportunities for growth for rural and urban communities. These systems that expanded to a significant degree shortly after World War II, have been challenged by a large set of factors including, among others, aging and deterioration; natural hazards, primarily climate and weather extremes; cyber and physical attacks; and shifting, and in some parts, increasing demands for infrastructure services, partly, because of increasing urbanization. The infrastructure needs have been increasing with systems and components reaching or passing their intended design lifetime, as this transition increases the rate of failure, and subsequently, the required replacement or costly maintenance and rehabilitation actions[5]. While local, state, and federal governments and public and private sectors have been investing in infrastructure, the needs have consistently exceeded investments, leading to a growing gap in infrastructure investments[2].

The nation's infrastructure was built long ago. As an example, parts of the power grid were built about a century ago, but a major expansion of the grid happened in 1950s and 1960s, with components and systems that had the design lifetime of about 50 years. Inspection of facilities built in 1960s and earlier have shown significant deterioration[6]. The traffic volume on bridges and roadways has increased by 18% from 2000 to 2019[2]. The increasing service demands along with aging have resulted in accelerated deterioration, which among other factors, have left 43% of our public roadways in poor or mediocre conditions and 7.5% of bridges (over 46,000 bridges) in the nation in poor conditions[2]. In many cities, there are considerable portions of underground wastewater collection pipelines that are a century old. Infiltration, exfiltration and

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[2] American Society of Civil Engineers, "2021 Report Card for America's Infrastructure" (Reston, VA), accessed July 14, 2021, https://infrastructurereportcard.org/wp-content/uploads/2020/12/National_IRC_2021-report.pdf.

[3] DHS, "Critical Infrastructure Sectors | CISA," accessed July 13, 2021, https://www.cisa.gov/critical-infrastructure-sectors.

[4] The scoring is based on regular assessment of the state of the infrastructure and considers multiple factors including capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation. See ASCE Infrastructure Report Card 2021 for more details.

[5] Yousef Mohammadi Darestani et al., "Life Cycle Resilience Quantification and Enhancement of Power Distribution Systems: A Risk-Based Approach," *Structural Safety* 90 (2021): 102075.

[6] PJM Regional Transmission Operator (RTO), "2019 Regional Transmission Expansion Plan (RTEP)," 2020, https://www.pjm.com/library/reports-notices/rtep-documents.aspx.

leakage are becoming more frequent, as these systems are aging and as traffic loads on our roadways are increasing, posing risks to public health and safety[7,8].

Resilience concerns of our increasingly deteriorating – yet increasingly vital – critical infrastructure are further compounded by climate and weather extremes. The built environment in the U.S. is exposed to a broad range of climate and weather hazards. Since 1980, the country has sustained 298 billion-dollar weather and climate disasters[9,10] with the total cost of these events exceeding $1.975 trillion. The observed trends in these losses are concerning. The number of billion-dollar weather and climate disasters has increased from 2.9 events per year in 1980s to 12.3 events per year in 2010s. In the same period, the average annual loss by such events has increased by a factor of 4.6 to $84.5 billion. In 2020, the number of billion-dollar disasters reached 22 incurring $98.9 billion in losses. Impacts of climate and weather extremes on our infrastructure have been significant. Historical data indicate that extreme weather events are the leading cause of power grid outages[11]. In the period of 1980 to 2012, the nation observed an alarming tenfold increase in the number of outages[12]. The compounding effects of aging and deterioration and stresses from extreme events can substantially increase grid failures[13,14]. The number of major power outages has remained high since 2012[15,16]. Power outages inflicted an annual average loss on the US economy of between $40 and $55 billion[17]. The lasting outages have also had detrimental impacts on public health especially for vulnerable populations[18,19]. Similarly, the impacts of climate and weather extremes on the transportation

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[7] Soroush Zamanian, Jieun Hur, and Abdollah Shafieezadeh, "Significant Variables for Leakage and Collapse of Buried Concrete Sewer Pipes: A Global Sensitivity Analysis via Bayesian Additive Regression Trees and Sobol'indices," *Structure and Infrastructure Engineering*, 2020, 1–13.

[8] Soroush Zamanian, Mehrzad Rahimi, and Abdollah Shafieezadeh, "Resilience of Sewer Networks to Extreme Weather Hazards: Past Experiences and an Assessment Framework," in *Pipelines 2020* (American Society of Civil Engineers Reston, VA, 2020), 50–59.

[9] A billion-dollar disaster refers to an event with the total incurred loss across all impacted areas exceeding $1 billion.

[10] NOAA National Centers for Environmental Information (NCEI), "U.S. Billion-Dollar Weather and Climate Disasters," 2021, DOI: 10.25921/stkw-7w73, https://www.ncdc.noaa.gov/billions/.

[11] Executive Office of the President., "Economic Benefits of Increasing Electric Grid Resilience to Weather Outages" (IEEE USA Books and eBooks, p29., 2013).

[12] Alyson Kenward and Urooj Raja, "Blackout: Extreme Weather, Climate Change and Power Outages," *Climate Central* 10 (2014): 1–23.

[13] Abdollah Shafieezadeh et al., "Age-Dependent Fragility Models of Utility Wood Poles in Power Distribution Networks against Extreme Wind Hazards," *IEEE Transactions on Power Delivery* 29, no. 1 (2013): 131–39.

[14] Yousef Mohammadi Darestani and Abdollah Shafieezadeh, "Multi-Dimensional Wind Fragility Functions for Wood Utility Poles," *Engineering Structures* 183 (2019): 937–48.

[15] Sayanti Mukherjee, Roshanak Nateghi, and Makarand Hastak, "A Multi-Hazard Approach to Assess Severe Weather-Induced Major Power Outage Risks in the Us," *Reliability Engineering & System Safety* 175 (2018): 283–305.

[16] Stephen A. Shield et al., "Major Impacts of Weather Events on the Electrical Power Delivery System in the United States," *Energy* 218 (2021): 119434.

[17] Richard J. Campbell and Sean Lowry, "Weather-Related Power Outages and Electric System Resiliency" (Congressional Research Service, Library of Congress Washington, DC, 2012).

[18] Joan A. Casey et al., "Trends from 2008–2018 in Electricity-Dependent Durable Medical Equipment Rentals and Sociodemographic Disparities," *Epidemiology (Cambridge, Mass.)* 32, no. 3 (2021): 327.

[19] Wangjian Zhang et al., "Power Outage: An Ignored Risk Factor for COPD Exacerbations," *Chest* 158, no. 6 (2020): 2346–57.

infrastructure have been significant. Over 57% of 1948 recorded bridge collapses in the U.S. until 2014 have been linked to hydraulic causes, e.g., flooding[20].

We are in a highly uncertain and increasingly volatile environment because of the changes in climate patterns, especially climate and weather extremes. We are not only concerned about single hazard types becoming more extreme, we are also concerned about the increasing likelihood of compound weather and climate events[21], where combinations of multiple climate drivers or hazards can lead to significant losses[22]. Climate change is anticipated to impact many hazards to the built environment. Projections indicate that the relative sea level along the coasts of the U.S. may rise by over 14 inches by 2080 under a low global mean sea level rise scenario[23]. This scenario is very likely to be exceeded under various climate change projections. This small rise in relative sea level will increase the annual frequency of damaging flood events by 25 times[23], which will have devastating impacts on buildings, energy and transportation infrastructure and other critical built and natural systems in coastal regions, and will extend the reach of coastal flooding to areas further inland. While there are differences in the projected impacts, studies generally indicate that stresses to the built environment in the United States will increase, and in some parts of the country the increase will be substantial[24].

Infrastructure design codes and standards have traditionally relied on statistical analysis of historical data to determine design loads for the intended service life of the systems. This approach would work well if the environment remains stationary meaning that there are no long-term temporal trends in loads. However, we are currently at a stage where we are observing trends that are changing loads. In addition, modern design codes for structures with new design philosophies and procedures were developed in late 1990s and early 2000s based on the lessons learned from past failures and research on the performance of structures[25]. Many structures in the nation's built environment, however, were designed and constructed long before modern standards and based on codes that are no longer considered adequate. In addition, changes in the characteristics of the environment over time, e.g., land use and its impacts, can result in conditions that significantly differ from those assumed during the design of infrastructure, therefore, posing risks that were not accounted for in the design process.

Projected Costs for Improving the Resilience of Critical Infrastructure

Proactive management of risks is substantially more effective than reactive strategies; however, insufficient resources have prevented infrastructure owners and operators from applying proactive measures in many cases. Instead actions are taken when failures occur or when the state of the infrastructure reaches a critical condition. The American Society of Civil Engineers has estimated that the investment gap in the nation's critical infrastructure has grown from $2.06

[20] Madeleine M. Flint et al., "Historical Analysis of Hydraulic Bridge Collapses in the Continental United States," *Journal of Infrastructure Systems* 23, no. 3 (2017): 04017005.
[21] Omid Mazdiyasni and Amir AghaKouchak, "Substantial Increase in Concurrent Droughts and Heatwaves in the United States," *Proceedings of the National Academy of Sciences* 112, no. 37 (2015): 11484–89.
[22] Jakob Zscheischler et al., "A Typology of Compound Weather and Climate Events," *Nature Reviews Earth & Environment* 1, no. 7 (2020): 333–47.
[23] William Sweet et al., "Global and Regional Sea Level Rise Scenarios for the United States," 2017.
[24] Donald J. Wuebbles et al., "Climate Science Special Report: Fourth National Climate Assessment (NCA4), Volume I," 2017.
[25] Jim Rossberg and Roberto T. Leon, "Evolution of Codes in the USA," *ASCE.< Https://Www. Nehrp. Gov/Pdf/UJNR_2013_Rossberg_Manuscript. Pdf>(Sept. 29, 2019)*, 2013.

trillion for the period of 2016-2025[26] to $2.59 trillion for 2020-2029[2] period. More detailed assessments of investment gaps by infrastructure type are available in ASCE's Report Card for America's Infrastructure[2]. These estimates of investments are primarily to address current and immediate future needs and to comply with current regulations. The investment needs will grow, if these systems are to be prepared for the anticipated stresses and expected service demands of the future. As an example, depending on the emissions scenario, 66,000 to 117,000 of the nation's bridges are estimated to be vulnerable to increased peak flow risks because of climate change[27]. The total cost for adapting to these increased risks alone ranges from $140 to $250 billion[28].

Solutions to Infrastructure Challenges
The nation's infrastructure plays a critical role for many activities of the society, in supporting the economy and serving the public safety and national security. As elaborated earlier, these systems, however, face a wide spectrum of near-term and long-term challenges in an environment that is highly uncertain and increasingly volatile. In order to prepare our infrastructure for such environments, I recommend the following solutions.

Strategic investments in our infrastructure
We are in an environment where risks to our infrastructure are not static but dynamic, the needs are evolving, and the environment is uncertain. In response, we need a long-term national vision for the resilience of our infrastructure with sustained investment plans for adaptive, robust strategies. Mitigation of hazard risks to buildings and other infrastructure systems are among the most effective ways to reduce losses and enhance the resilience of the built environment. Cost-benefit studies of such investments have shown high benefit to cost ratios in the order of 11 to 1 for adopting the latest building codes, 4 to 1 for above-code design of buildings, and 4 to 1 for applying common and practical retrofit measures to our existing building stock[28]. Every dollar spent on resilience investments for businesses has reduced business interruption losses under major hazards by over $4.5. Retrofitting bridges and hardening the power grid are shown to yield significant benefits over the life of these systems[29,30,31]. To maximize gains, the mitigation investments must consider strategies that improve infrastructure resilience against multi-hazard risks[30,32]. Moreover, early application of climate adaptation measures to deficient infrastructure can substantially reduce adaptation costs[28]. A critical point to note here is that infrastructure stakeholders including owners, operators, and users may not be able to afford the

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[26] American Society of Civil Engineers, "2017 Report Card for America's Infrastructure" (Reston, VA), accessed July 14, 2021, https://2017.infrastructurereportcard.org/wp-content/uploads/2019/02/Full-2017-Report-Card-FINAL.pdf.
[27] Len Wright et al., "Estimated Effects of Climate Change on Flood Vulnerability of US Bridges," *Mitigation and Adaptation Strategies for Global Change* 17, no. 8 (2012): 939–55.
[28] Multi-Hazard Mitigation Council, "Natural Hazard Mitigation Saves: 2019 Report" (Washington, DC: National Institute of Building Sciences, 2019), https://www.nibs.org/files/pdfs/NIBS_MMC_MitigationSaves_2019.pdf.
[29] Ehsan Fereshtehnejad and Abdollah Shafieezadeh, "A Multi-Type Multi-Occurrence Hazard Lifecycle Cost Analysis Framework for Infrastructure Management Decision Making," *Engineering Structures* 167 (2018): 504–17.
[30] Nariman L. Dehghani, Ashkan B. Jeddi, and Abdollah Shafieezadeh, "Intelligent Hurricane Resilience Enhancement of Power Distribution Systems via Deep Reinforcement Learning," *Applied Energy* 285 (2021): 116355.
[31] Nariman L. Dehghani, Chi Zhang, and Abdollah Shafieezadeh, "Evolutionary Optimization for Resilience-Based Planning for Power Distribution Networks," in *Nature-Inspired Computing Paradigms in Systems* (Elsevier, 2021), 47–61.
[32] Jieun Hur and Abdollah Shafieezadeh, "Multi-Hazard Probabilistic Risk Analysis Of Off-Site Overhead Transmission Systems," in *SMiRT-25* (Charlotte, NC: IASMiRT, 2019).

upfront costs of resilience projects, even for cases where the benefit to cost ratio is high. Therefore, resilience strategies may need to be incentivized through measures such as reduced insurance rates and premiums; federal, state or local grants for resilience strategies; tax incentives; mortgages and loans for mitigation plans; and improved resilience-based codes[33].

As resources are limited, the short- and long-term infrastructure needs must be characterized and prioritized[34,35]. We must develop and apply tools for life-cycle cost and life-cycle performance (e.g., life-cycle resilience[36]) analysis to evaluate infrastructure projects. Future projects should have funding plans that cover maintenance, operation, and end of service life costs, in addition to the initial costs of projects. Reliable characterization and prioritization of needs require extensive data from the built environment. Facilitating the application of sensing technologies at large scales to various elements of our existing and new infrastructure along with broadband communication and technologies such as digital twin to collect, transfer, process, and learn from the data can enable highly effective proactive risk management for our infrastructure systems.

Integration of equity considerations in risk distribution into infrastructure decisions

Apart from technical challenges, we face very important questions at the interface of science and policy about the distribution of risks. Socioeconomically vulnerable communities are taking a higher share of infrastructure disruption risks relative to the rest of the population. This disparity manifests in both hazard exposure and impacts of disruptions. In all stages of resilience response including pre-disaster mitigation projects as well as infrastructure and community recovery, we should consider the eventual impacts and benefits for different populations in the society, especially the vulnerable populations, to ensure that the risks are equitably shared.

Support research and development for resilient infrastructure and communities

Infrastructure resilience is a highly complex problem with significant knowledge gaps in many areas including, among others, (i) evolving characteristics of hazards, (ii) physical and operational performance of the built environment during and in the aftermath of extreme, uncertain conditions of natural hazards, (iii) interactions of built, natural, and human systems over time and space, and (iv) innovative technologies and strategies that enable robust, adaptive, and cost-effective pathways to infrastructure resilience in the evolving uncertain hazard environment. We must increase investment in basic and applied research to address these gaps in science and technology. Moreover, critical infrastructure resilience research is often hampered by limited access to reliable integrated and spatially explicit data related to infrastructure and hazard impacts. Policies are needed to require critical infrastructure owners and operators to collect and make the data available. This step, in addition to benefiting research to understand and enhance resilience, will lend to a transparent environment where

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[33] Multi-Hazard Mitigation Council, "Developing Pre-Disaster Resilience Based on Public and Private Incentivization" (Washington, DC: National Institute of Building Sciences, 2015), https://www.nibs.org/files/pdfs/NIBS_MMC_ResilienceIncentivesWP_2015.pdf.

[34] Ehsan Fereshtehnejad, Abdollah Shafieezadeh, and Jieun Hur, "Optimal Budget Allocation for Bridge Portfolios with Element-Level Inspection Data: A Constrained Integer Linear Programming Formulation," *Structure and Infrastructure Engineering*, 2021, 1–15.

[35] Ehsan Fereshtehnejad et al., "Ohio Bridge Condition Index: Multilevel Cost-Based Performance Index for Bridge Systems," *Transportation Research Record* 2612, no. 1 (2017): 152–60.

[36] Nariman L. Dehghani, Yousef Mohammadi Darestani, and Abdollah Shafieezadeh, "Optimal Life-Cycle Resilience Enhancement of Aging Power Distribution Systems: A MINLP-Based Preventive Maintenance Planning," *IEEE Access*, 2020.

infrastructure stakeholders can learn about the performance of service providers and make informed decisions for risk management.

Thank you,

Abdollah Shafieezadeh, Ph.D.
Lichtenstein Associate Professor
Department of Civil, Environmental and Geodetic Engineering
The Ohio State University
Columbus, OH