Uncertainties in Design Standards Create a Barrier for Long-Term Disaster Recovery: A Case Study of the West Virginia Bridge Home Program

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Abstract
West Virginia was ravaged by devastating flooding across its central and southern regions in June of 2016 by a 1,000-year storm event. Many residents in the rural areas of the affected regions rely on private bridges to access their homes from state-maintained roadways. The flooding destroyed hundreds of these bridges and created a need to replace them. This research explores the challenges stemming from a lack of up-to-date and widely accepted design standards for private bridges. Interviews were conducted with 15 stakeholders, including mayors, disaster workers, government agencies, engineers, and others, to identify these challenges and best practices. A reoccurring theme in interviews was the role liability played in inhibiting the nonprofit and private sectors from contributing to the project. The solution to this issue came through in-person meetings where the public agencies listened to the concerns of the technical experts and nonprofit sectors, and all parties agreed to continued collaboration throughout the project. These meetings helped build trust among the stakeholders, which decreased the perceived liability among the engineering firm and nonprofit sector organizations and enabled the project to proceed. The resulting design of the bridges – although relatively simple to design, build, and maintain – has proved resilient in recent years. The design principles, which incorporated resilience as a best practice, could be replicated in future flood recovery efforts, and adopted into an updated set of private water crossing guidelines to ensure future recovery efforts are not relying on outdated engineering practices.

Introduction

Communities have never been in greater need of resilient infrastructure, given both the historical and projected increases in the intensity and frequency of storm events. The recent flooding in Eastern Kentucky, the devastation caused by Hurricane Ian across Florida and the Carolinas, and the devastating 2021 European floods are the latest in many examples demonstrating the need for more resilient infrastructure. These severe storm events cause devastation but also create the opportunity to construct new, more resilient communities. Resilience is “the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events” (National Academies Press, 2012). The 2016 West Virginia floods were used as a focusing event, and the post-disaster long-term recovery process was examined – specifically, the design, permitting, and construction of private residential bridges – to better understand how to build more resilient communities and the current barriers to this process.

Many homes in the affected areas of West Virginia require these bridges for access. These bridges may not reach the level of societal importance facilities like hospitals and power plants do, but to the residents who rely on them to access their homes, they can mean the difference between life and death. This is evidenced by cases such as a resident, who, only one day after their bridge was replaced by the Bridge Home Program, had a medical emergency, and was taken away in an ambulance. Emergency services used the bridge to reach the resident’s home.

Background and Research Question

Deciding how to rebuild after a disaster is difficult, given that the previous standards used to construct the infrastructure led to failure. New standards that better account for the type of disaster the community recently experienced and future forecasted events take time to develop. New standards are often not available by the time recovery begins. Engineers and project stakeholders are left to make design and construction decisions using the same guidelines and standards in place before the disaster event. Building back to the same standards leaves the community vulnerable to similar future events.

The research presented in this paper explores what happens in the absence of up-to-date design standards and guidelines during the long-term recovery process. People who experience flooding view themselves as more vulnerable to future flooding and tend to have greater intentions of taking precautionary measures against future flooding than non-flood victims (Zaalberg et al., 2009). Similarly, the expectation in West Virginia was that stakeholders responsible for designing and building back communities would be motivated to ensure their projects could resist future similar disaster events. However, the financial burden of these design decisions may still drive recovery decisions. In a survey of over 9,900 eligible voters in the United States and Germany, Fesenfeld & Rinscheid (2021) found that people's sense of urgency was a critical factor for supporting "low-cost" climate mitigation efforts but that it did not lead to support for more burdensome measures. In other words, upfront costs were still a greater priority than long-term resilience. The research question the study presented in this paper attempted to answer was how do uncertainties in design criteria affect long-term recovery efforts.

Research Methodology and Approach

Multiple types of infrastructure projects were considered. However, private residential bridges were chosen due to a lack design standards before and after the flooding event in West Virginia in 2016. Before the flooding, a nonprofit disaster recovery organization, the West Virginia Voluntary Organizations Active in Disaster (WV VOAD), created the WV Bridge Home Program. This program brought together nonprofits, such as Mennonite Disaster Service (MDS) – an organization that helps homeowners rebuild after disasters, engineering firms, and local, state, and federal government agencies to address the issue of private bridges washing out due to flooding events already occurring throughout the state.

Communities in West Virginia like White Sulphur Springs, Clendenin, Rainelle, and Elkview were unprepared for the nearly 10 inches of rain that fell in under 48 hours in June 2016. The region's mountainous topography and historical development on flat land near streams led to infrastructure being built in low-lying areas, which left them vulnerable to flooding. In many areas, state roads were built on one side of the stream while homes were built on the other and connected using a private residential bridge like the one seen in Figure 1.

Figure 1: Poorly Designed Private Residential Bridge Before Bridge Home Program Replacement (Courtesy of WV VOAD)

These bridges are the homeowners' responsibility and are not maintained by any government entity. The design and construction of private residential bridges pose unique challenges. They are not common in all parts of the country, homeowners usually have limited funds to design, construct, and maintain them, and their location in the floodway makes them especially vulnerable to damage from flooding. This vulnerability led to homeowners' bridges being inundated by raging floodwaters in the 2016 floods, causing hundreds of bridges to be severely damaged or destroyed.

The WV Bridge Home Program, in its infancy prior to 2016, became an instrumental mechanism for getting hundreds of residents safe access to their homes following the 2016 floods. The program began because residents would call the Department of Transportation (DOT) after smaller flooding events asking for help reconstructing their bridges after the original bridge (often built decades early) was damaged or destroyed. The DOT had to deny residents' requests for assistance because the state agency could not take responsibility for the bridges on private property. WV VOAD saw this growing need throughout the state and assembled a diverse team of government agencies, nonprofits, and an engineering firm to address this issue. The program has produced over one hundred safe, low-cost, and resilient private access bridges since the flooding event in 2016 (see Figure 2).

Figure 2: Private Residential Bridge After Bridge Home Program Replacement (Courtesy of WV VOAD)

The bridges are described as resilient because they are secured in place by driving micro piles down to bedrock or refusal, the curbs allow water to flow through them during flood conditions, the bridges span from bank to bank, and the banks are stabilized using riprap or gabion baskets. These design elements were decided on after the structural engineer conducted numerous site visits of bridges destroyed during flooding in the area in 2015. He found that many of the bridges failed by water overturning them, pushing them off their foundations, or eroding the banks – causing them to fall into the side of the streambed. These design elements significantly reduce the risk of these failure modes occurring. There is a much lower chance of the bridge being overturned or pushed off its foundation due to the abutments being secured to bedrock using the micro piles. Similarly, to reduce the transverse loading from the water and the additional force from debris buildup, the bridge curbs were designed to allow water and small debris to flow through them. Spanning from bank to bank preserves the natural width and height of the stream to the greatest extent possible, thus preventing abutments from being undermined when water flow increases. Additionally, it places the bridge at the highest practical height to allow the maximum amount of water to flow beneath it.

Lastly, the banks are less likely to experience severe erosion because of the protection offered by the riprap or gabion baskets. Bank stabilization is a common practice and was mentioned in a FEMA report titled "Private Water Crossings: Considerations before you build or rebuild" (FEMA, 2009). The FEMA report, while it mentions bank stabilization as a best practice, also endorses the use of wingwalls. Wingwalls are commonly used as a source of protection for bridge abutments, however, they are often designed in a way that infringes on the sides of the stream, thus restricting the natural flow of water at the bridge location. This makes them susceptible to undermining during high water events. For this reason, wingwalls were not used for any of the Bridge Home Program bridges. Several of the Bridge Home bridges have experienced flooding that submerged the bridge despite the fact the oldest of these bridges are still relatively young at an age of approximately seven years old. After the floodwaters receded, the bridges were completely functional and only required minor work to reestablish the bank stabilization.

Additional benefits of these bridge designs are that they are environmentally conscious (elevated above the streambed), easy to build, and require minimal maintenance. By keeping the bridge out of the stream there is little disruption or damage to the natural habitat. This is a major benefit of the design since one of the towns most severely impacted by the 2016 floods, The Town of Clendenin, is home to the Guyandotte Crayfish – an endangered species that lives in streams and stream banks. The bridges require minimal construction knowledge and skill to build, thus they can be built using volunteer labor, and they are low maintenance. Owners sign a maintenance agreement upon completion of the construction of the bridge stating they will replace wooden boards that make up the bridge decking and reestablish bank stabilization after flood events as needed.

Data Collection
Semi-structured interviews were the primary method of data collection. A combination of convenience and snowball sampling was utilized. Stakeholders were identified, and additional interviewees were recruited based on recommendations provided by stakeholders during the interviews. When possible, site visits were made to observe the construction process. The site of the private residential bridge serving as the model project for the WV Bridge Home Program, called Big Blue, was visited by members of the research team several times. Notes, photos, and videos were recorded during these visits. Additionally, documents, such as government grants, engineering drawings, permits, and laws, were identified and used as supporting documents for the interviews.

Interviews were conducted from June to September 2022, except for two pilot interviews, which were conducted in October 2021. A total of 15 people from ten organizations participated in the semi-structured interviews. Interviewees included mayors and FEMA officials, professional engineers, and nonprofit disaster workers. Interviews lasted approximately one hour. Stakeholders were identified using documents from the WV VOAD Bridge Home Design Guidelines, which identified various Bridge Committee members and advisors who created the program, as well as recommendations from WV VOAD's Executive Director. Stakeholders included the public, private, and nonprofit sectors and hold varying roles and degrees of involvement with the Bridge Home Program.

Interview questions were drafted by the primary investigator to explore how three topics – stakeholder relationships, government regulations, and stakeholders' perceptions of risk – affect long-term infrastructure design and construction post-disaster. These questions were then reviewed by four researchers familiar with the research project. The primary investigator modified the interview questions based on feedback aimed at limiting bias and considering the local culture. One such example is the rewording of a question phrased "were you thinking of how to build back better" to "were you thinking about how to build it better than it was before". This may seem like a small change, but the researchers did not want political opinions surrounding the then recently passed "Build Back Better Act" to influence the interviewees' responses. In another example, a recent study, as well as media coverage in 2020, suggested that Republican-dominated communities that are not as receptive to the concept of climate change are supportive of taking steps to increase their community's resilience and future risk capacity (Giordono et al., 2020). Given this, questions tended to use phrasing around resilience rather than climate change. One such question was, "how big of a role does the idea of resilience play during the design and permitting process?".

Data Analysis
Data analysis involved using software to transcribe interviews, then the research team reviewed and corrected the transcriptions. Thematic content analysis was then used to derive meaning from the interview data by assigning codes to group comments reflecting similar themes. Nvivo software was used to perform the thematic content analysis. An initial set of codes were established before any analysis, and additional codes were added during analysis. Creating an initial set of codes before

performing analysis is a form of deductive coding (Yin, 2011). Generating new codes during the analysis aligns with an inductive approach as it allowed the relevant themes and concepts to emerge from the data (Yin, 2011). This hybrid approach balanced the benefits of both an inductive and deductive methodology.

The researcher established two levels of codes. The first level of codes represented three topics of interest – (1) stakeholder relationships and the organizations involved in recovery, (2) legal and regulatory concerns, and (3) stakeholders' perceptions of future risk. These codes were used to highlight phrases that addressed questions like who was involved in each recovery activity, what laws, permits, or other regulations were they considering, and what risks were affecting decision-making. The second level of codes showed more specific subtopics. For example, when an organization involved in the recovery process was mentioned by an interviewee that comment was coded under the organizations code within the topic one (relationships) code set. Many of the themes fit under the umbrella of one of the three topics; however, some themes were broader and were established as high-level, standalone codes. An example of this is the design considerations code which can apply to all three topics. Figure 3 below shows an example of some of the codes used and their hierarchy.

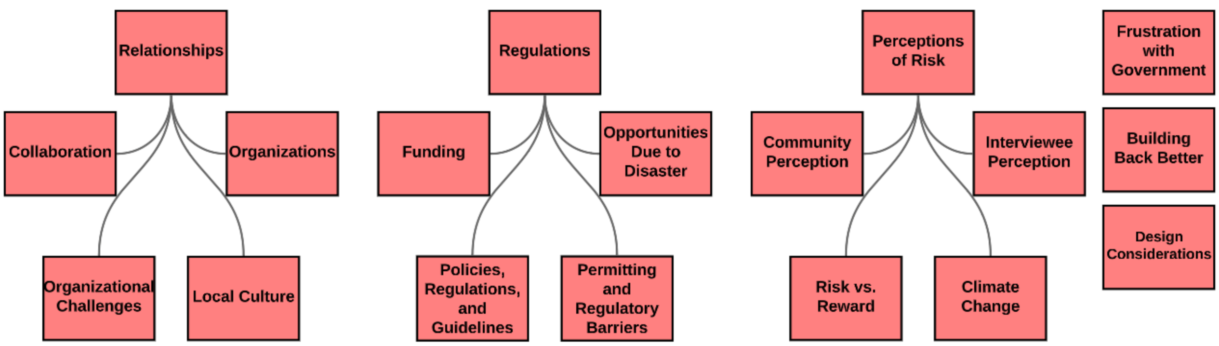

Figure 3: Example of Coding Hierarchy

Many of the interviewees' comments fit into one topic and subtopic, such as the mention of a specific type of permitting into the permitting and regulatory barriers subtopic of topic two (regulations); however, some comments were relevant to multiple topics and subtopics, in which case more than one code was applied. An example of a subject coded more than once was from a FEMA Emergency Management Specialist. She discussed challenges associated with rebuilding a substantially damaged school in Clendenin, WV. Federal regulations deemed any work done to repair or reconstruct the school to be the same as a new build. Discussions with locals ensued about relocating the school, but was met with resistance due to the history associated with the school building. Her comments were coded as both "building back better" and "permitting and regulatory barriers" because they involve restrictions tied to government recovery funds to rebuild the school outside of the floodplain, rather than rebuild to the pre-disaster state.

Validation of Coding

The coding for this research was validated by using a negotiated agreement approach to establish an intercoder reliability score. This type of approach describes a process in which two researchers code a subset of the transcripts, compare their codes, and then discuss differences to resolve discrepancies (Campbell et al., 2013). The PI created the coding scheme and an independent, third-party coder with no prior exposure to the research was brought in as a validator.

There is no universally accepted sample size for establishing intercoder reliability, but recent literature supports using 10 – 25% of data units (O'Connor & Joffe, 2020). As such, a sample size of three interviews was used for this study. The sample transcripts were from two professional engineers and a public permitting agency.

The PI discussed the research study with the validator, explained the coding scheme, and reviewed how to operate the NVivo software. The validator independently coded the three interview transcripts, then NVivo was used to calculate a Cohen's Kappa (K) intercoder reliability score (ICR) for each. The average initial ICR across the three transcripts was K = 0.54. The PI and validator met to discuss differences and found that many of the discrepancies between codes involved a lack of expertise by the validator on topics such as engineering design and disaster recovery regulations. After several iterations of discussion between the PI and validator, a final Cohen's Kappa of K = 0.90 was established across the transcripts.

Key Findings

One prominent theme emerging from the interviews was the importance of risk, specifically professional liability, related to uncertainty associated with the lack of design standards for private access bridges. Design uncertainties increased the perceived liability for the bridge designers and contractors involved in the recovery making them less inclined to participate. The biggest concern was the lack of standards for the design of private access bridges. The bridge engineer explained that engineers typically rely on industry-accepted standards to guide their design process. Without those standards, engineers and contractors are hesitant to become involved. The bridge engineer, who eventually designed many of the bridges alongside WV VOAD, expressed:

> "So I think probably the biggest reason we got involved was, um, maybe a liability issue. First of all, there is no code for residential bridges, so for a firm to go and stick their neck out with the liability issues. And so, yeah, liability is a concern for me. – Professional Engineer, JZ Engineering

The Executive Director for Mennonite Disaster Service (MDS), one of the organizations that helped build the bridges emphasized the liability issue by recalling an experience over a decade earlier in 2004, saying:

> "We drove up and down all over West Virginia, seeing the need for private access bridges. I got excited and I thought this is something MDS could do. But we ran into a roadblock and that was liability. If we build these bridges, these are on private land, but if a five-ton coal truck delivers coal in the winter and they break through this bridge. Who's liable? Who are they going to sue?" – Executive Director, Mennonite Disaster Service

MDS was not willing to take on the liability of building these bridges on its own over a decade before because of the liability concerns. It took WV VOAD's leadership, government cooperation, and the engineering provided by JZ Engineering to overcome the challenges an effort like the Bridge Home Program faced.

Standards provided by the State or Federal Government are often used by design professionals to justify their decision-making and ensure their design is in line with accepted norms and practices. Without any accepted standards for designing private bridges, the engineering team had little guidance to help justify their design decisions. Such void in guidance may lead to overdesigning in an effort to limit their liability by ensuring the infrastructure is far more resilient. In this case, overdesigning was not feasible, given the financial constraints of the WV Bridge Home Program. This is where the theme of collaboration and value of organizational relationships became evident. The good working relationship and sense of trust among the stakeholders that decreased the perceived liability became instrumental in ensuring the project team was willing to design and construct the new bridges. The Executive Director for the Mennonite Disaster Service said:

> "We had EPA, we had floodplain managers. We had personnel from FEMA and Washington, D.C. come, and we had JZ Engineering and a number of other people. Twenty or thirty of us in that room, and we started talking about the various issues and challenges that we had, and in that room, we discovered a way that MDS could effectively build a bridge and local authorities and the state authorities said, yeah, we can provide liability coverage. We can work with you on endangered species. We can work with you on the roads and highways as far as setbacks and so on."

Everyone involved desired to help victims of flooding, but the uncertainty behind the design guidelines and permitting created liability that no one volunteer organization or engineering firm was able to accept. The shared goal of rebuilding would not have been possible without the various stakeholders collaborating to pool resources and take shared ownership of the program to limit the liability on any one party.

The ongoing discussions between stakeholders throughout the project were critical to overcoming the uncertainty in the design criteria.

> "It took us probably ten months to come up with the guidelines and the process and the engineering and everything that we were going to do. It probably took us at least 10 months of meeting daily, sometimes through the week and sometimes weekly." – Executive Director, West Virginia VOAD

These discussions served to develop technical designs and figure out logistics, but they also created a sense of community and a shared vision. At the end of the first meeting, one of the participants described the sentiment this way:

> "We're here to help each other, not stand in each other's way…I said, you know, I can't believe this is happening here. And someone just said, 'Well, we live here. These are our hollows, these are our bridges, these are neighbors not getting to the hospital. We have to make it work.'"

The trust and good working relationship among nonprofit and private entities ultimately made the project more tenable across parties where everyone shared responsibility and liability for its outcomes. Communities coming together and working collaboratively on disaster recovery is not a new phenomenon. Studies have found that knowledge developed through experiencing past disasters makes people more likely to cooperate (Cassar et al., 2017; Toya & Skidmore, 2014). This strengthened sense of community can be a valuable asset. In a similar manner, lack of coordination and effective management is a commonly cited barrier to effective recovery (Safapour et al., 2021). As such, having a single person coordinating efforts to ensure organization and limit duplication of effort is important (Rouhanizadeh & Kermanshachi, 2020, 2021). The Bridge Home Program was a success because there was effective leadership, which created an environment that capitalized on stakeholders' desire to collaborate with one another for the good of their community.

Implications

The uncertainties in design criteria led to an unwillingness among the design team to participate in the project and ultimately was resolved through collaboration among all the major non-public entities agreeing to share liability. The bridge designer believed the lack of design guidelines from the State or Federal Government increased their liability due to the lack of a benchmark on which to base their design decisions. Overcoming this barrier required government agencies to work alongside nonprofits and private sector organizations to decrease perceived liability.

Uncertainties in design criteria for private residential bridges pose a barrier to future recovery efforts. West Virginia, and other mountainous regions requiring similar infrastructure, will continue to experience flash flooding in the future. The long-term recovery process could be streamlined through Government agencies adopting private bridge design and construction guidelines to promote the resiliency of the methods used in the WV Bridge Home Program and provide a measure of liability protection to stakeholders who abide by those guidelines in future design and construction projects. Guidelines should not be overly prescriptive to the point that engineering judgment is constrained because the design for each bridge varies based on individual homeowners' needs and the surrounding environment's conditions. The WV Bridge Home Program is a nationally renowned model whose fundamental design principles and collaborative efforts among stakeholders could be replicated.

Limitations and Future Work

The oldest of the Bridge Home Program bridges are approximately seven years old, so a long-term study of their performance has not yet been possible. Although the effects of repeated exposure to long-term flooding have not been possible yet, the bridges have performed as expected under flood conditions during that time span. Revisiting these bridges in the future and evaluating their condition immediately following future floods are two methods that could provide additional, valuable insight into their strengths and vulnerabilities.

Future work should also begin to explore if there is a threshold for a disaster to be a catalyst for change. The flooding event of 2004, mentioned by the Executive Director of Mennonite Disaster Service (MDS), did not result in the same type of response as the flooding in 2016. A better understanding of why each event led to different responses is essential to identify the factors that motivate change and how to predict it. For example, future work could explore the difference in the number of bridges destroyed, public outcry, economic and social impact, availability of resources, or political will between the two cases. The WV Bridge Home Program being established prior to the 2016 floods but not before the 2004 floods likely also contributed to the difference in response. Creating public-private working groups at the state or local level around vulnerable infrastructure is a model that needs further study. Preemptively creating these working groups, before a disaster occurs, helps open lines of communication, build trust among local partners, and helps identify the gaps in design guidelines that could hinder future recovery when a disaster occurs. These types of working groups are relatively inexpensive compared to the cost of infrastructure. Understanding their impact and monetary savings after an event is a necessary next step.

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