Impact of 2021 Western European Flooding on Geo-Structures

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ABSTRACT

Between July 14–16th, 2021, record rainfall and subsequent flooding resulted in the deaths of over 200 people and billions of dollars-worth of damage in Germany and Belgium. An NSF sponsored Geotechnical Extreme Events Reconnaissance (GEER) Association reconnaissance mission was undertaken by the authors to investigate the effects of flooding in Germany, Belgium, and the Netherlands. The two-week-long mission provided insight to the performance of various geostructures such as building foundations, roads, and bridges. This paper provides a summary of observations made by the US-based GEER team in collaboration with many local European colleagues. Key observations presented include a bridge case study, the impact of scour and erosion on different structures, and soil-structure interactions. A review of the data used to inform the reconnaissance mission as well as the data collection technologies used, including terrestrial LiDAR, UAV-Structure from Motion (SfM), and multispectral imagery, is also presented.

INTRODUCTION

From 1995-2015, floods comprised 43% of all natural disasters worldwide (UN/CRED 2015) and a rise in mean global temperatures has, and will continue to, result in increases in extreme rainfall events across the world (Tabari 2020; Ingram 2016; IPCC 2013, Trenbeth 2003). One such event occurred July 14-15th, 2021 over Western Europe when a storm system called "Bernd" set record-setting amounts of rainfall in Germany, Belgium, the Netherlands, and other western European countries. This extreme rainfall event and subsequent flooding resulted in over 220 deaths in Germany and Belgium (thelocal.de 2021; lesoir.be 2021). In the hardest hit region, the Ahr Valley in Germany, water levels rose over 9 m, submerging entire residential structures that were near the river banks. In addition to residential homes, infrastructure assets that sustained heavy damage include roadways, bridges, and various lifeline facilities.

With the goal of collecting perishable data and documenting the effects to geotechnical infrastructure, an international team of engineers was formed and mobilized from the US-based Geotechnical Extreme Events Reconnaissance (GEER) Association. The GEER team established contacts with and collaborated with scientists and engineers from Germany, Belgium, and the

Netherlands during the reconnaissance mission in order to better understand the conditions leading up to the event and how certain systems responded. Site visits in Germany were concentrated on the Ahr, Erft, and Urft rivers Aug 8 - Aug 15th, 2020; site visits in Belgium were concentrated on the Vesdre and Meuse rivers Aug 16-17th; site visits in the Netherlands were concentrated on the Geul and Roer rivers on Aug 18th. The following sections of this paper will describe data collection methods used by the GEER team to collect perishable data, general observations of damage including an overview of the performance of geotechnical assets, and a case study of a bridge failure in Trooz, Belgium.

DATA COLLECTION METHODS

Due to ongoing relief and recovery efforts, the GEER team responded to the events approximately one month after the impact. Due to the perishable nature of post-disaster data, it was of vital importance to conduct site visits as soon after the event as possible. Data collection tools used in the reconnaissance mission include: Terrestrial Light Detection and Ranging (LiDAR), unmanned aerial vehicles (UAVs), multispectral imagery, terrestrial photography, on-site measurements, on-site soil sampling, and interviews with local residents. In addition, satellite imagery was used extensively in planning the mission. From optical UAV imagery, 3D structure from motion (SfM) models were developed, which allow for a more in depth forensic investigation into the geometries of assets of interest. This type of investigation was also performed from LiDAR data.

Data is inherently lost during the clean up after an event and what is presented is not a complete accounting of all effects of the flooding, but rather the visible effects from one month after the effect. The goal of using these data collection tools is to better understand both the underlying hazard characteristics, such as water level, flow velocity, and extent, but also the impacts on geotechnical assets. Documenting the damage, or lack thereof, from the flooding event is crucial in determining failure mechanisms and how to build back more resiliently.

GENERAL OBSERVATIONS

Roadways

Damage to road infrastructure, included bridge destruction, embankments erosions, road washouts, and collapse of noise barriers (Figure 1). Germany's Rhineland area reported more than 130 kilometers of damaged roads, amounting to more than 100 million euros in repair costs (Autobahn.de, 2021). Within the Ahr valley, over 74 kilometers of roads, paths, and bridges have been (critically) damaged. In some cases, repairs are expected to take months to years (Zeit Online, 2021). In the Eifel region, major freeway sections, such as the Autobahn A1/A62 intersection near Erftstadt-Blessem will be closed for repairs until at least early 2022 (Wehmann, 2021). The district of Euskirchen reported road damages accumulating to 4.4 million.

Belgium experienced less road damage than Germany, however selected critical infrastructure points were also strongly affected. For instance, the major freeway tunnel (Cointe) in Liege which connects freeways E40 and E25, was completely flooded and remains closed until summer 2022. The tunnel, which allowed passage of more than 75,000 vehicles per day, requires a repair budget of 50 million euros (BRF Nachrichten, 2021). Even though most road infrastructure was flooded within the affected regions of the Netherlands, no major road damage was reported.

Figure 1a shows road damage in Chaudfontaine, Belgium. Shoulder pieces and railing are broken off, debris and deadwood remains entangled in the road remains. The subsurface layers are washed out, and geotextile is loosely hanging below the concrete layer. Figure 1bshows the collapse and erosion of the Autobahn A1 near Erftstadt-Blessem. This freeway section is located adjacent to the major floodplains of the river Erft and failure is associated with the draw-in of floodwaters into the Blessem gravel mine. One of the 2 lane offramp onto the A1 freeway, as well as its shoulder and noise barrier were destroyed. Large-scale erosion, with nearly landslide type of soil movement, was the main driver to this failure. The freeway intersection remains closed until spring 2022 (Wehman, J., 2022). Figure 1c shows road damage in Ahrweiler, caused by erosion of the embankment area and subsequent loss of stability. Consequently, utility lines, such as gas, electricity, water/wastewater and telecommunication networks were exposed and damaged. Figure 1d shows a similar embankment erosion to the road shown in Figure 1c. This damage was more complex and extended over several kilometers, including damage to nearby bridges and major wastewater pipelines.

Residential Homes

The flood-related damage to insured properties reported by the Germany Insurance Union (GDV) accumulates to 4.5 -5.5 billion Euros (GDV, 2021). This amount constitutes primarily damage to residential houses and some business infrastructure. In the Ahr valley in Germany, the flood washed away at least 467 buildings along the river, including at least 192 residential homes (Schmid-Johannsen et al., 2021). Stores, hotels, factories and other manufacturing facilities are either severely damaged, non-functional or completely destroyed by the water. Of the 4,200 buildings along the Ahr River, more than 3,000 (>70%) are estimated to have been damaged. Most residents chose to rebuild their houses, 35 of them did not receive permission to rebuild (SWR.de, 2021)). In the Eifel region, eight houses were destroyed in Erftstadt-Blessem, which were located near the edge of the crater that formed around the floodplains of the Erft river near the Blessem gravel mine. In the heavily destroyed town of Pepinster, Belgium, 20 buildings were reported to have completely collapsed during the flood, a total of 50 mostly residential buildings have been severely damaged or destroyed in Pepinster's city center (Brusseltimes.com, 2021). The high water on the Maas river tributary in the Netherlands caused problems with 2,300 homes in the municipality, 700 of which were seriously damaged. Damages are estimated to be around 200 million euros (NLtimes, 2021).

Typical damage patterns were difficult to assess given the substantially different locations, and flood characteristics, however in areas with high flood velocities, primary damage was frequently observed to facades parallel to the flow direction. Newer houses that were washed away were often built in full or partial prefabricated houses (e.g., modular construction), with the weak point being the connection between the matt foundation and the superstructure.

Bridges

The most consistently observed infrastructure asset that was observed to have sustained substantial damage are bridges. Bridge damage was observed to be the most significant and densely distributed in the Ahr Valley region. Significant damage to a number of bridges was also observed along the Vesdre River southeast of Liege, Belgium. In the Ahr Valley region in Germany, 62 bridges were destroyed out of the 112 that were along the 40km long stretch of the

Ahr River that experienced severe flooding. At the time of the reconnaissance mission one month after the event, 35 of the 112 bridges were operational. Of the bridges that were still in place, destroyed or not, damage was concentrated in three main areas: pier foundations, abutment foundations, and decks.

Figures 1 a-d: Observed building damage in various locations. a (Top Left): Chaudfontaine, Belgium (Lat: 50.58694, Lon: 5.65004); b (Top Right): Autobahn A1, Erftstadt-Blessem, Germany (Lat: 50.81338, Lon: 6.78907); c (Bottom Left): Ahrweiler, Germany (Lat: 50.53880, Lon: 7.10424); d (Bottom Right): Bad-Neuenahr Ahrweiler (Lat: 50.54669, Lon: 7.17881).

The bridge decks were overtopped in many areas, resulting in mass accumulation of debris. This debris often adds significant weight to the deck and signs of large impact forces were also visible in many areas. Scour and erosion along pier and abutment foundations were present in a majority of bridges observed whose piers and abutments were still in place. The presence of many tilted piers also provide evidence of scour leading to differential settlement; large impact forces could have also contributed to this observation. As a remediation effort, riprap scour protection was added after the event in many areas in order to prevent further damage to the foundations. Access to some regions without a bridge was impossible via automobile. In these situations, the Technisches Hilfwerk (German Emergency Response) and German military constructed temporary bridges in the Ahr Valley.

Figures 2 a-d: Observed building damage in various locations. a (Top Left): Walporzheim, Germany (Lat: 50.53245, Lon: 7.06271); b (Top Right): Pepinster, Belgium (Lat: 50.56925, Lon: 5.80531); c (Bottom left): Walporzheim, Germany (Lat: 50.53264, Lon: 7.06146), d (Bottom right): Altenahr, Germany (Lat: 50.516144, Lon: 6.988238)

Figure 3 shows three bridge failures with different degrees of remediation efforts. Figure 3a shows the location of a previously small, pedestrian bridge that was lifted off of the abutments and washed out with little other visible damage. Figure 3b shows the previous location of a two-lane road bridge that connects two sides of the city of Valkenburg, Netherlands over the Geul River. Scour and erosion around the abutments led to the ultimate failure of this urban bridge. Figure 3c shows the failure of piers for a rail bridge in Germany. Minor tilting can be seen in the standing pier and the fallen remnants of another pier can be seen in front of the standing pier.

This bridge was located in one of the most severely damaged regions in the Ahr Valley, where scour and erosion not only destroyed this bridge, but washed away hundreds of homes as well.

Figures 3 a-c: Three observed bridge failures observed in the reconnaissance mission. a (Top Left): Goffontaine, Belgium (Lat: 50.57217, Lon: 5.76563); b (Top Right): Valkenburg, Netherlands (Lat: 50.86523, Lon: 5.82950); c (Bottom): Mayschoß, Germany (Lat: 50.51815, Lon: 7.02690).

Figure 4 a-b: Ry Fenderie bridge in Trooz, Belgium. Photographs taken via mobile phone. (Lat: 50.57080 Lon: 5.68953)

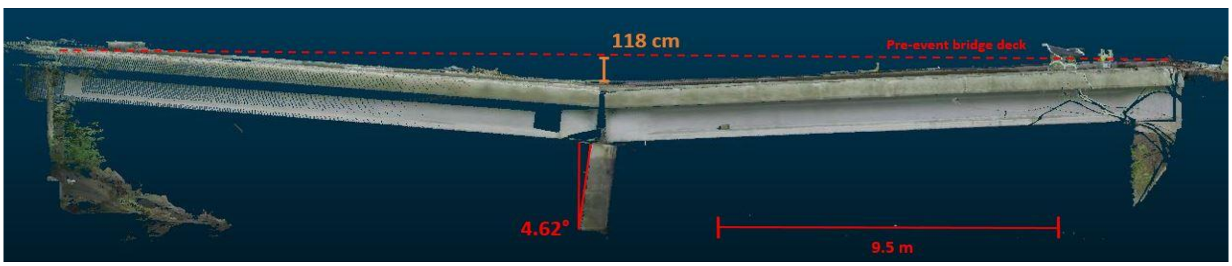

Figure 5: 3D point cloud data of Trooz, Belgium bridge, showing 4.62° tilting of the pier and 118cm vertical displacement of the bridge deck. Data obtained via Leica RTC 360 medium-range LiDAR scanner.

CASE STUDY: BRIDGE IN TROOZ, BELGIUM

Trooz, Belgium is located on the northern bank of the Vesdres River, the most heavily impacted region in Belgium. This classic beam bridge across the Vesdres provided a unique opportunity for the GEER team due to it being still standing, displaying obvious signs of damage, and there being little traffic around the study area to disrupt the collection of geospatial data. Two LiDAR scans of this bridge were taken; access points to the bridge were limited due to safety concerns and topographical constraints not allowing for convenient positioning of the LiDAR scanner. The bridge was still open to pedestrian foot traffic at the time of the visit, but was demolished as late as October 2021. A temporary bridge for pedestrian foot traffic has been built in its place.

The bridge measured approximately 30m across and has an unknown construction date. From collected LiDAR data (Figure 5), it has been estimated that the bridge pier tilted ~4° to the west and that the middle of the bridge deck settled 118cm. It is unknown if the bridge deck had begun sagging pre-event, therefore total settlement of the pier due to scour and erosion to the foundation cannot be confirmed. A future study on scour and erosion mechanics and force required to move the pier 4° will be conducted.

CONCLUDING REMARKS

The documentation and reporting of damage in a post-disaster environment one month after the event proved difficult due to the perishable nature of the data. Reconstruction efforts were progressing in the easily accessible regions, while significant humanitarian work was still ongoing in other regions, making coordination with local agencies and authorities integral to the success of the mission. Common points of damage observed by the GEER team include building foundations, road embankments, and foundations of bridge piers and abutments due to scour.This paper serves as merely an overview of the damage observed in the affected regions. The full report can be found on geerassociation.org and all data is made open access on designsafe-ci.org.

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