Downstream Impacts on Geostructures of the Michigan Dam Failures

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ABSTRACT

The breaching of the Edenville dam and overtopping of the Sanford dam on May 19, 2020 have been the focus of significant geotechnical investigation, while considerably less scientific focus has been directed towards documenting the resulting damage to highway embankments, bridges, and homes downstream of the dams. The Geotechnical Extreme Events Reconnaissance (GEER 2020) Association deployed a small team to conduct field reconnaissance after the event with the goal of making preliminary observations of impacts to geostructures downstream of the Edenville and Sanford dams. Damage was concentrated in the city of Sanford while in the city of Midland, downstream of Sanford, flood waters did not reach heights that caused significant damage to bridges or property. The observations made by the GEER team suggest that bridge abutments, buried utilities in earthen structures, and timber-framed buildings downstream of dams and other high risk flood zones warrant additional considerations during design to increase resilience during extreme events.

INTRODUCTION

Over the span of May 18th and 19th, Midland County received 10.62 cm of rain (NOAA 2020). As a result, the 16.46 m high Edenville Dam was breached and the 7.92 m high Sanford dam was subsequently overtopped on the afternoon of May 19th, 2020 (Gladwin County, Department of Energy 2021). Flood waters from the failed embankment dams reached a record 10.67 m, which surpasses the level of "Major Flood" by 2 m (USGS). The downstream impacts necessitated the emergency evacuation of approximately 11,000 people; 2500 buildings were damaged and resulted in over $175 million in damages (Matheny, 2020). This report documents an initial review of the impacts of the flooding on geostructures. It has been developed based on publicly available reporting and through a field reconnaissance trip conducted by a GEER team on June 2, 2020.

A two-person GEER team traveled to affected regions on June 2nd, two weeks following the original dam failures; the path taken by the team can be seen in Figure 1. The GEER response included documenting impacts and other field observations with georeferenced images, taken using the mobile application Filio (www.filio.io). A forensic study of the Edenville and Sanford dams was outside the scope of the GEER team response, which focused on the downstream impacts to geostructures and buildings.

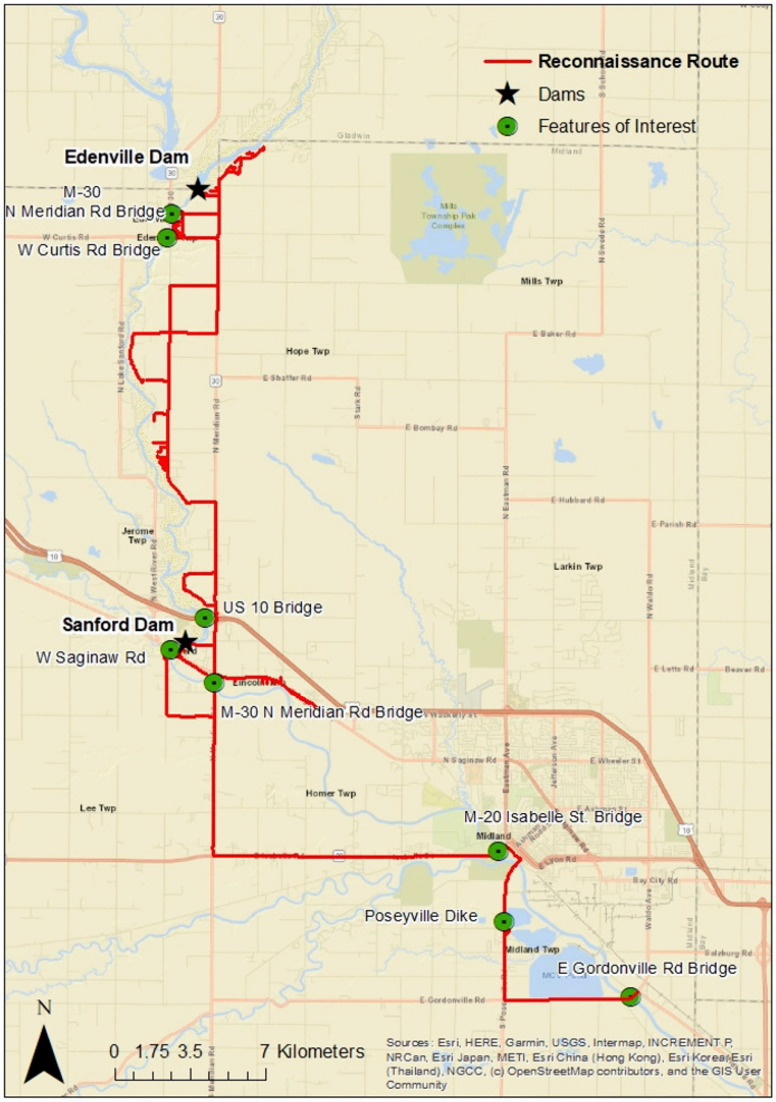

Figure 1. Path travelled by the GEER team on June 2nd, 2020 (GEER 2020) and locations of observed damage.

SUMMARY OF IMPACT ON GEOSTRUCTURES

Bridges

As a result of the disaster being closely contained to Lake Wixom, Sanford Lake, and the Tittabawassee River, the majority of the geostructures impacted by this event were bridges. This section will discuss the impacts on 10 bridges that were visited by the GEER team, moving from north to south along the Tittabawassee River. The south end of the M-30 bridge (43.80552, -84.38616) south of Wixom Lake experienced a 19 meter-wide embankment failure, which resulted in the collapse and washing away of a 14 meter stretch of road between the sloped embankment and the first set of pile foundations (Figure 2). The southern approach to the embankment displayed a significant amount of slumping towards the river, exhibited by guardrail piles that have up to 1 meter of vertical sediment eroded, leaving the bottoms of many guardrail piles south of the failure also completely exposed and unsupported. The scouring of the M-30 bridge embankment left the driven pile foundations and cast-in-place pile cap exposed. The 5 meter long vertical and internal raking piles showed minor damage but no evidence of any movement.

Figure 2: M-30 Bridge embankment failure

Moving south into the town of Edenville, soil markings on a piled dock structure (43.80272, -84.38628) indicate that the structure experienced uplift of 0.3 m of the near-shore row of piles and 0.5 m in the land-side row of piles due to a pontoon boat being forced underneath the dock and then raised by flood waters. Both rows of piles also showed signs of a further 0.3 m of scour. The impacts on the W. Curtis Rd bridge (43.79899, -84.38800), roughly 0.3 km downstream of the pile dock structure, were more severe on the west abutment than the east. While there was slight displacement of riprap scour protection underneath the east abutment, there was no apparent scour at the base of the abutment and the geomembrane was not displaced. Across the river on the west end of the bridge, scour exposed the foundation of two rows each of 13 driven piles. In addition, the pile cap was fully exposed and any evidence of prior riprap scour protection had been completely washed away.

Further south, the US-10 bridges over Sanford Lake (43.68558, -84.37055) were under construction for repairs at the time of the GEER mission, but nonetheless showed evidence of extensive scour erosion along the abutments. As a result, the bridge pile foundations became exposed, although the pile foundations showed no signs of damage themselves. Significant amounts of the bridge approach abutment and approach slab were missing and assumed to have washed away by flood waters, which overtopped the bridges. In addition, the embankments on either side of the bridges were exposed by the flood waters, which were in the process of being repaired at the time of the GEER mission.

The town of Sanford was the location of not only the most dramatic building damage, but also road and bridge damage. As evidence by the trees, sand, and water on top of the W. Saginaw Road bridge in Sanford (43.67458, -84.38649), the flood waters overtopped the bridge as well as the adjacent Pere Marquette bike path, which is built on top of a dis-used railway embankment. The eastern side of the bridge approach embankment experienced a 167 meter long failure and complete collapse, and displayed scour depths of up to 8 meters (Figure 3). The uplift and displacement of the road shoulder revealed the difference in fill beneath the shoulder and main road. The shoulder was placed on two layers of hot mix asphalt (HMA) approximately 12 cm thick overlaying 9 cm of asphalt concrete, whereas the main road fill consisted of 7.5 cm of HMA overlaying 10 cm of asphalt concrete, which then overlaid 20 cm of reinforced concrete. Pieces of asphalt 25 m^2 in size were ripped up and carried by floodwaters and then deposited in lawns and in front of businesses. Of the 167 meters of embankment and road failure, all of the asphalt was either missing or significantly displaced. The base of the eastern abutment for the W. Saginaw Rd bridge experienced scour reaching upwards of 0.33 m in the middle of the abutment and 0.5m at the northern pile cap. Although the pile cap was exposed, the pile itself remained underground and no damage was observed to the structure of the abutment or the piles. There was significant accumulation of trees, roots, and other various flood debris against the eastern abutment, which also showed signs of historic concrete corrosion at the pier head and failures of badly corroded duct brackets along the side of the bridge.

Figure 3: W Saginaw Rd approach embankment failure

Located 60 m downstream from the W. Sagniaw Rd bridge, the Pere Marquette bike path (43.67453, -84.38763) was also overtopped by 2 meters of water, but showed significantly fewer signs of damage. The lack of built-up debris along the path was stark in comparison to the W. Saginaw Road bridge, as transported sandy sediment was the only artifact remaining from the flood. The eastern side of this repurposed railway embankment experienced a maximum of 0.5 meters of slumping along the abutment, which was correlated to the location of a drainage pipe. The N 7 Mile Road Bridge (43.67361, -84.38945) is located over the Salt River, a small tributary of the Tittabawassee River and about 200m southwest of the Pere Marquette bike path. At the time of the visit, there were ongoing efforts to repair a gas pipeline that may have been damaged in the flooding, which is located on the north end of the bridge and runs orthogonal to the bridge. There was no visible damage to the abutments, embankments, or any other part of the structure visible from the north end of the bridge, meaning the work on the gas pipeline could have been precautionary.

Another M-30 bridge (43.66527, -84.36856), located on N. Meridian Road, passes over the Tittabawassee River and is about 2 km southeast of the N 7 Mile Road Bridge. Evidence of large tree branches and other debris stuck in the bridge girders reveals that water levels reached at least the base of the bridge. While debris was present, the extent of debris was dramatically smaller than that of the W. Saginaw Road Bridge, 2 kilometer away. There was no visible damage to this bridge; scour and displacement of scour protection was not observed. The in-river piers and approach viaduct also showed no signs of damage.

In contrast to the aforementioned bridges, the M-20 bridge on Isabella St (43.61354, -84.25072) is located in the heart of the city of Midland. Located at the base of the abutment, dessication cracks were present on top of the rip-rap scour protection, indicating it had not been replaced at that stage. No evidence existed to suggest any significant amount of the riprap had been displaced, although a 6 cm thick piece of asphalt beneath the bridge, which acted as a walkway for a nearby park, had been completely fractured in multiple locations and displayed 3 m of offset In the park adjacent to the M-20 bridge a three-way wooden footbridge (43.61107, -84.24870) connects the Chippewa and Tittabawassee Rivers, and experienced water levels that reached the bottom of the bridge, as evidenced by debris in the girders and sand deposits at the entrance to all sides of the bridge. The northern most third of the bridge showed no signs of structural damage. The western third of the bridge displayed about 5cm of scour at the end pier, but otherwise no damage. The southern most third of the bridge is at the intersection of a cutbank for the Tittabawassee River and a point bar for the smaller Chippewa River. This section of the bridge showed minor dislodgement of slabs of concrete scour protection and 0.33 m of exposed wooden piles The displacement of concrete slabs coincided with minor slope failures at the base of the abutment, which was the cause of the exposed wooden column.

The southernmost bridge visited located about 14 km southeast of Sanford Dam, the E Gordonville Rd bridge (43.56977, -84.19435), displayed no signs of scour or other damage to the abutments, scour protection, or piles, which had been the most prominent displays of damage in the other bridges visited. This bridge also displayed no signs of excessive debris buildup or anything that would indicate the bridge had been overtopped with water. Downstream of the Edenville and Sanford dams, bridge abutments and scour protection were the two most common locations where damage was concentrated. In addition, previously buried utilities were often found in close proximity to points of failures and should be given closer consideration when designing against high water levels and high flow velocity.

Buildings

As observed by the GEER team, building damage was constrained to two main areas: between the M-30 and W. Curtis Rd bridges in Edenville and the town of Sanford, along W. Sagniaw Rd. Of the four observable residential buildings along the eastern bank of the Tittabawassee River, three homes sat upon the top of an approximately 8 m high slope, all of which experienced an intrusion of flood waters. The one home that was not atop the slope sat approximately 2 m above regular water level and was completely swept off of its foundation and washed away. Floodwater left deep scours in the foundation and the riverbank adjacent to the home; the kitchen floor and part of the foundation were still visible and all else was washed away (Figure 4). The home directly next to the destroyed home has a foundation that rests at the same height above the regular water level, but has taller stories built into the side of the higher slope to provide more stability. This home experienced catastrophic flooding on multiple stories, although the extent of structural damage is unknown.

Figure 4: Exposed foundation of home near the bank of the Tittabawassee

In the city of Sanford, four residential homes along W. Saginaw Rd and W. Center St were swept off of their foundations and washed away in the flood waters; four residential other homes and two commercial buildings were also heavily damaged in the flood. Damages to these buildings ranged from severely flooded to significant foundational damage due to scour. The commercial properties on the corner of W. Center St and W. Saginaw Rd had the front of the building foundation and sidewalk completely washed out; a drainage pipe underneath the sidewalk and a sewer drain were still present in the area and could have contributed to this failure (Figure 5).

Figure 5: Sidewalk and road failure plus foundation damage due to scour

Poseyville Dyke

On the morning of May 20th, emergency officials ordered an evacuation of people living on Ashby Road due to the breaching of the Poseyville Dike (43.59656, -84.24758). The purpose of this dike is to protect residential homes from the potential flooding of the Midland Cogeneration Venture plant cooling ponds, which is the largest gas-fired cogeneration plant in the country. The dike failure occurred at a pump station where a buried pipe underneath the dike embankment pumps excess water back into the pools on the non-road side of the dike; the piping is a possible contributing factor to the overall failure. In addition to the failure of the dike and its embankment, one lane of the adjacent S Poseyville Rd was destroyed due to significant scour, which reached depths of 2.1 m. The dike embankment failure exposed the foundation of the pump station, including two piles. The pile on the west end of the station, closer to the road, had 1.8 m of exposure and the eastern pile, closer to the ponds, had 1.2 m of exposure. The 0.3 m thick base slab at the top of the piles was also exposed, with visible water marks reaching 1.3 m above the top of the base slab of the station (Figure 7). An overlook of the ponds, less than 1 km directly south of the Poseyville dike, provided an opportunity to see that there was no evidence of damage to any of the cooling ponds or any part of the cogeneration plant.

Figure 6: Poseyville Dike failure

Utilities

A number of utilities were severely damaged or destroyed downstream of the two dams due to flood waters, and even more were uncovered and exposed via scour. An electricity pylon (43.61301, -84.25056) at the M-20 bridge in Midland showed no signs of scour, denting, or any other forms of damage. Flood water depths in this area were at least 3m based on water markings on nearby playground equipment. As mentioned in the previous section, there was ongoing remedial work needed to reinforce a gas pipeline (43.67361, -84.38945) at the N 7 Mile Rd bridge, which was likely only precautionary as there was no visible damage to the surrounding earth or bridge. On the eastern side of the Sanford Dam, a new substation (43.67612, -84.38020) structure was fully submerged by flood waters at peak flood water height, but at the time of the visit, there was no visible damage due to the already receded flood water. There was wooden debris in the surrounding fencing and fresh gravel at the base, meaning significant work had been done in the days between the flooding and the GEER response to repair the substation. Surrounding the substation fencing are sand deposits left by flood waters and minor slope failures, which indicates that the substation likely located in a high-energy environment and was made a priority in the first stages of cleanup.

The area surrounding the W Saginaw Rd embankment failure also contained five instances of severe damage to utilities. Firstly, powerlines were strewn across the W Saginaw Rd bridge (43.67458, -84.38649) from flood waters and in some instances partially buried beneath sand, pavement, and other debris. Secondly, piping was exposed underneath the collapsed road that was completely in-tact and had no visible damage other than being completely exposed to the surrounding environment. No evidence exists to support the idea that the approach embankment failure was due to an underlying pipe failure, contrary to other observed failures from this event. Observations of the Poseyville Dike, commercial properties' foundations on W Saginaw Rd, and the east abutment of the repurposed railway embankment adjacent to the W Saginaw Rd bridge all included evidence of damage to buried pipes that were exposed via scour. Thirdly, at the Village of Sanford Park (43.67595, -84.38591), whose southern boundary is W Saginaw Rd, one light post, one fallen telecom pole, and a series of telecom wires were found to be partially or nearly entirely buried beneath flood sand deposits (Figure 7). Drainage pipes and minor slope failures were also observed along the banks of the Tittabawassee River and the park. Additionally, the PVC piping alongside the W Saginaw Rd bridge showed severe sagging and bending due to the rusted and broken brackets holding it in place. Lastly, the GEER team observed gas seepage along the side of commercial buildings on W Saginaw Rd, although the source of these gas streaks could not be identified. Four separate and distinct oil slicks were also identified to be running into the Tittabawassee River between the M-30 bridge in Edenville and the W Curtis Rd bridge.

Figure 7: Burial of light post beneath sand deposits from flood water

CONCLUSIONS

The focus of the GEER field reconnaissance was to document the extent and types of damage in the downstream region resulting from the breaching of the Edenville dam and overtopping of the Sanford dam on May 19, 2020. This paper seeks to provide an overview of this damage but does not include detailed analysis of any of the causative mechanisms including scour bearing capacity or settlement. The lack of detailed flood water velocity and height data as a function of time would make such analysis speculative. Equally well, the evidence resulting from the field reconnaissance efforts suggest consideration should be given to hardening similar structures that might be subjected to similar flood waters at other locations in the future. Given the relatively rare nature of such events, focus on hardening solutions should emphasize minimizing costs while providing moderate protection. Such measures might include designing gradual transitions between structures and adjacent elements, placement of additional rip-rap in key locations and raising of selected critical structures as appropriate.

This paper provides a detailed depiction of the downstream effects of the Edenville and Sanford Dam failures rather than the more heavily studied dam failures. In summary, ten bridges downstream were observed, eight of which were damaged enough to be closed. In addition, five residential houses were observed to be swept off their foundations, with dozens more buildings damaged due to high water levels and scour to the foundation. Along the observed dike failure (Figure 6) and the approach embankment (Figure 3), buried utilities were exposed and thought to be an initiation point for failure. These observations by the GEER team show how vulnerable downstream communities are to dam failures from heavy rainfall. Risk analysis and monitoring of dams are a common standard, but it is a recommendation of this paper that a larger effort be put into assessing the vulnerability of communities downstream of dams and the potential flooding extent downstream during heavy rainfall events.

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