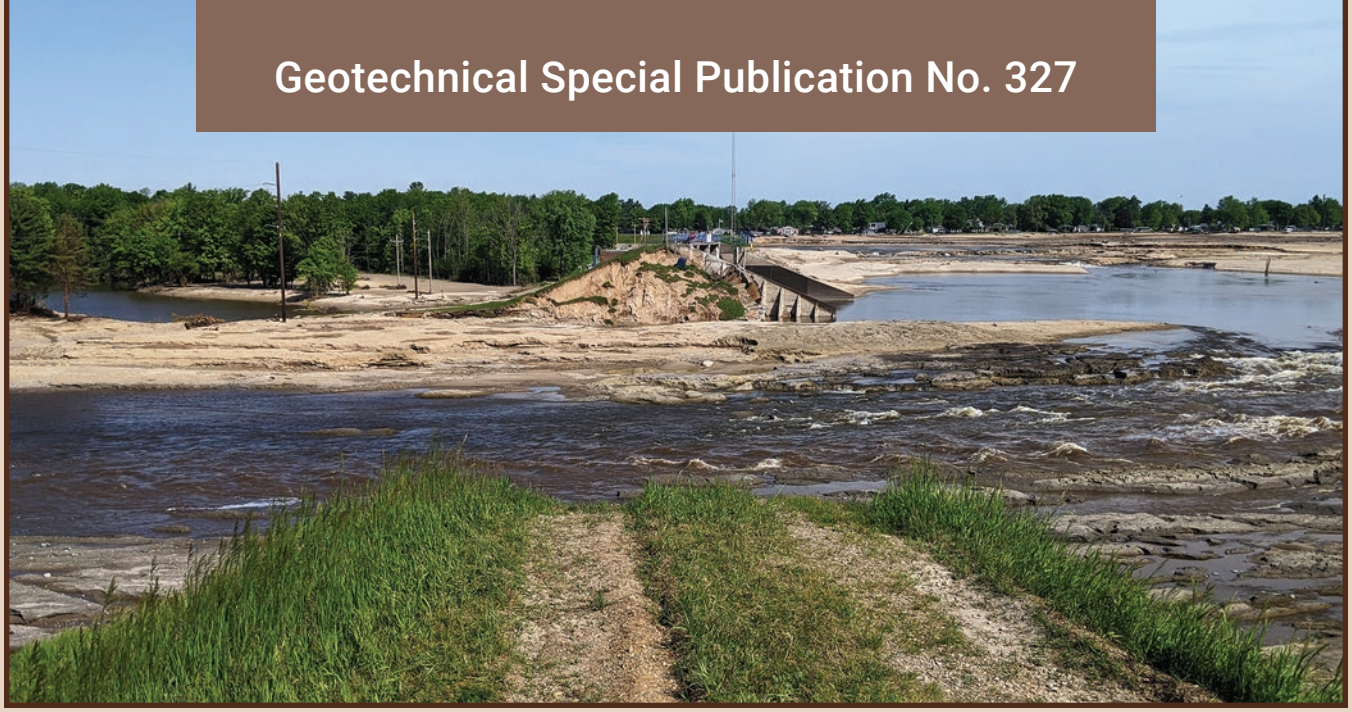
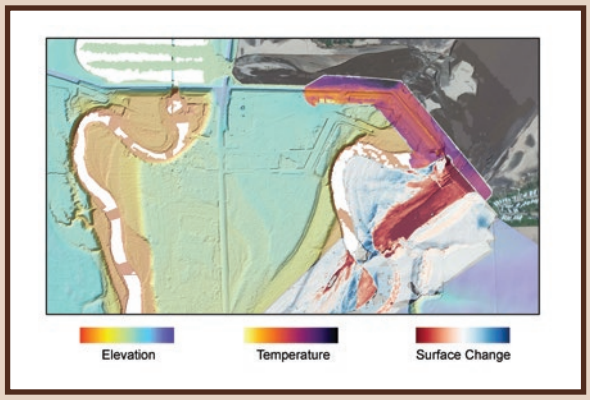
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Edenville and Sanford Dam Failures

Field Reconnaissance Report



PREPARED BY

Embankments, Dams, and Slopes Committee

EDITED BY

Daniel Pradel, Ph.D., P.E., D.GE

Adam Lobbestael, Ph.D., P.E.

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Authors

Daniel Pradel, *Lead*, The Ohio State University

Adam Lobbestael, *Co-Lead*, NTH Consultants, Ltd.

Adda Athanasopoulos-Zekkos, University of California, Berkeley

Colin Brooks, Michigan Technological University

Cassandra Champagne, University of Michigan

Marin Clark, University of Michigan

Richard Dobson, Michigan Technological University

Douglas Edmonds, Indiana University

Alan Esser, SME

Weibing Gong, University of California, Berkeley

Madeline Hille, University of Michigan

John Manousakis, Elxis Group

Nicholas Marion, Michigan Technological University

Harrison Martin, Indiana University

Nikolas Midttun, University of Michigan

Nathan Niemi, University of Michigan

Thomas Oommen, Michigan Technological University

Kirk Townsend, University of Michigan

Brian Yanites, Indiana University

Dimitrios Zekkos, University of California, Berkeley

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The last two decades have revealed the vulnerability of our infrastructure to storm surges, flooding, slope movements, and construction activities, as well as the disastrous consequences, both human and economic, when failure of embankments, dams, slopes, levees, and flood control structures occur. The failure modes and structures involved in many of these extreme events fall within the area of expertise of the Embankments, Dams, and Slopes (EDS) Committee and can provide important lessons for designing and constructing more resilient infrastructure. The EDS Committee asked the Geo-Institute (G-I) for funding to investigate two major extreme events involving embankments, dams, slopes, levees, and other flood control structures per year. G-I funded this proposal and the reconnaissance of the Edenville and Sandford Dam failures is the first event investigated under the funding provided by G-I. Experienced volunteer geospatial researchers also participated from Michigan Technological University. G-I funds are only used to reimburse travel or investigation costs with an emphasis on encouraging younger EDS members to participate in the reconnaissance teams. Additional costs are borne by non-younger committee members that are selected to participate in the reconnaissance trip. The deliverables for each reconnaissance trip are (1) a report on the reconnaissance trip and recoverable perishable information, and (2) an article for *Geo-Strata* magazine, both of which have been delivered. The EDS Committee gratefully acknowledges the support provided by G-I that has allowed committee members to learn from field observations and improve future performance.

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Executive Summary

Two dams located north of the town of Midland, Michigan, failed and another two were damaged in May 2020, following heavy precipitation ranging between 9.7 cm (3.8 in.) and 20 cm (8 in.) over a two-day period. The Edenville Dam experienced a slope instability on May 19 that was captured in a video by a bystander and failed catastrophically. Waters released by the breach of Edenville Dam overwhelmed Sanford Dam, which was overtopped and failed on the morning of May 20. In response to the failure of Edenville Dam, around 11,000 people living in or near the town of Midland, Michigan, were evacuated in less than 12 h during the COVID-19 pandemic.

To collect perishable data on both dam failures, the Geo-Institute Embankments, Dams, and Slopes Committee mobilized a team that investigated the Edenville and Sanford Dam failures and performed

- Aerial reconnaissance, primarily of Edenville Dam and surrounding area, using optical, thermal, and light detection and ranging (LiDAR) sensors flown from unmanned aerial vehicle platforms, with three-dimensional optical data also collected of Sanford Dam;
- Geophysical testing of Edenville Dam adjacent to the breach, including seismic surveys for P-wave and S-wave depth profiles and electrical resistivity surveys;
- Geological reconnaissance of exposed slopes of Edenville Dam and scoured surfaces in the Wixom reservoir to assess the nature of geological materials comprising the dam foundation and the geomorphology of the predam surface topography;
- Geotechnical sampling and laboratory testing (including moisture, density, grain size distribution, shear strength, and permeability testing) of selected earth materials from Edenville Dam;
- Geotechnical observations of postfailure conditions, instrumentation, and subsurface drainage systems at Edenville Dam; and
- Research and review of historical documents, aerial photographs, and prefailure LiDAR and satellite data.

Edenville and Sanford dams are earth dams built between 1923 and 1925 for hydroelectric power generation, hence designed before the modern geotechnical engineering practices pioneered by Karl Terzaghi were widely accepted and constructed before Ralph Proctor's quality control assessment techniques for earth fill compaction were proposed.

Edenville Dam was constructed predominantly of poorly graded sand (SP), without a clay core, and with an unusual subdrainage system (consisting of loosely connected clay pipes), which is prone to obstruction from long-term use. Edenville Dam's upstream and downstream slopes have approximately 2.5H:1V (horizontal to vertical) and 2H:1V ratios, respectively. Importantly, the dry densities of the earth fills were low (i.e., limited compaction energy was used), the shear strength was low, and the downstream slopes were steep. The low shear wave velocities, obtained using geophysical testing techniques, were consistent with low fill densities.

In the years preceding the failure, published satellite data suggest that movement was occurring in the approximate area where the Edenville Dam failure occurred on May 19. Aerial photographs, prefailure LiDAR data, and ground photographs taken during recent periodic dam inspections show that the downstream slope of the dam in the vicinity of the failure area was uneven and had bulges and oversteepened areas, which are consistent with slope movement.

Geologically, the foundation of the dam is constructed primarily on Quaternary glacial till and outwash sands deposited during the retreat of the Saginaw Lobe of the Laurentide Ice Sheet around 14,000 years ago. Postglacial incision into the tills and outwash sands by the Tobacco and Tittabawassee Rivers resulted in the development of flights of fluvial terraces that represent past river base-levels. The dam is constructed across these terraces, resulting in lateral variations in both the dam thickness and the composition of geologic foundation materials at the base of the dam. We also observed a charcoal layer that underlies the dam materials in the section of the Edenville breach, which likely formed owing to forest clearing by logging and burning prior to dam construction. Our geologic interpretation is that the initial failure of Edenville Dam occurred entirely within earth fill materials. However, movement of the slope in preceding years may be related to differential settlements of the earth fill related to the presence of the previously described fluvial terraces.

Analysis of the video taken during the failure of Edenville Dam strongly suggests that the failure was circular in nature. Water jets are seen emanating from the slide mass during the failure and in the last frames of the video the soils from the sliding mass are flowing and appear to be liquefied as they spread along the toe of the dam. Although insufficient data exist to ascertain the actual mode of failure, two possible mechanisms are postulated: (1) Static liquefaction: Loading from the rise in reservoir elevation resulted in static liquefaction of the dam's earth fill, causing the downstream slope to fail from the resulting loss of strength. (2) Slope instability: The rise in reservoir elevation resulted in increased pore-water pressures and shear stresses that combined, permitted the development of a conventional rotational slope failure. During the failure, the slide debris, which was contractive in nature, flowed and became liquefied as it accumulated along the toe of the dam.