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On the Cover

Wolf Creek Dam is on the Cumberland River in South Central Kentucky near Jamestown, Kentucky. It provides flood control, hydropower, recreation, water supply, and water quality benefits for the Cumberland River system. Construction began in 1941 and was interrupted by WWII from 1943 to 1946. The reservoir was impounded in December 1950. The 5,736 foot-long dam is a combination earthfill and concrete gravity section. U.S. Highway 127 crosses the top of the dam.

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- Providing public awareness of the role of dams in the management of the nation's water resources;
- Enhancing practices to meet current and future challenges on dams; and
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GEOTECHNICAL ASSESSMENT OF INDIANA DAMS AND LEVEES DURING THE JUNE 2008 MIDWEST FLOOD

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ABSTRACT

During early June 2008 severe weather conditions and heavy precipitation impacted the central and southern portions of Indiana, with portions of the White and Wabash River basins receiving over 10 inches of rainfall. On 9 June the President issued a State of Emergency Proclamation and declared 30 counties in Indiana a major disaster area opening up the region to receive federal aid and FEMA assistance. Considering the heavy flooding experienced and the continued forecast of heavy precipitation, emergency assessments of all high hazard regulated dams in all counties declared disaster areas were undertaken. On 12 June the authors were deployed and provided support as part of efforts to provide real-time geotechnical evaluations of Indiana dams and levees which had been and were being stressed by record pool levels and river crests in order to provide a basis for risk-related decision-making. From this work, this paper provides many examples of observed geotechnical conditions posing threats to earthen structures including overtopped dam erosion, spillway erosion, downstream embankment erosion, slope failure, and underseepage-related foundation erosion. Examples are provided of how implemented recommendations such as recommending emergency downstream evacuations, keeping tail water on boils rather than pumping, sand bagging, closely documenting areas where distress was observed, and recommending future remedial investigation and construction contributed to minimization of current and future risk and real-time prioritization of resources during this event. Additionally, this paper serves as an example of ways to effectively approach similar emergency efforts in the future, such as having up-front compilation of all project data, utilizing GPS and GIS, having good communications established, and having experienced teams ready to deploy. Observed conditions and reconnaissance challenges during the June 2008 Midwest Flood demonstrate the need for proactively recognizing and addressing potential geotechnical-related risks associated with many of the Nation’s high hazard dams and levees.

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INTRODUCTION

Thunderstorms produced very heavy rainfall across portions of central and western Indiana (Figure 1A), starting the evening of June 6, 2008, and continuing through the

Figure 1. Maps of Indiana showing: (A) County boundaries and major rivers; and (B) 7-day total rainfall amounts ending the morning of 8 June 2008.
next morning. Nearly 11 inches of rainfall were recorded during this short time period in some areas as shown in Figure 1B. This resulted in almost instantaneous and extreme loading conditions on many of the dams located throughout the state and record stages along the White and Wabash Rivers during the following week. Runoff from this rainfall event affected a large number of water retention structures in central and western Indiana. More than 100 privately-owned, high-hazard dams located in Brown, Bartholomew, Johnson, and other nearby counties south of Indianapolis were loaded up to or in excess of their design maximum capacity from the runoff generated during this event. Due to the intensity and short duration of the rainfall event, supplemental geotechnical personnel were required by the State of Indiana to perform evaluations on all the dams to ensure public safety. Therefore, the Louisville District of the U.S. Army Corps of Engineers (USACE) was called upon to assemble a team of geotechnical personnel and provide technical field support for areas affected by this storm. The team consisted of 12 experienced geotechnical professionals (who typically stand ready to deploy for such events) and included four personnel from the USACE Huntington District. The team was paired with personnel from the Indiana Department of Natural Resources (IDNR) who assisted in finding dams, communicating with dam owners, and evaluating the structures.

Subsequent to the flash rainfall event that impacted the state dams, river stages on the White and Wabash Rivers continued to rise and at some locations reached record levels. These rivers reached crest elevations equal to or greater than the height of protection at several flood damage reduction levees and resulted in overtopping at some locations. The levees observed and evaluated by the team assembled for this event were predominantly agricultural levees that were generally remote, extensive in length, and showed signs of significant seepage-related distress. This paper provides examples of observed geotechnical conditions posing threats to earthen structures, and discusses these observations along with challenges associated with the dam and levee evaluations performed during the June 2008 Midwest Flood. These observations and challenges demonstrate the need for proactively recognizing and addressing potential geotechnical-related risks associated with many of the Nation’s high hazard dams and levees.

**DAM RECONNAISSANCE BACKGROUND**

Heavy precipitation which occurred in early June 2008 caused extensive flooding in south central Indiana. Considering the heavy flooding and the forecast for heavy rains, emergency assessments of all high-hazard, and State-regulated (non-USACE) dams in all counties declared disaster areas were deemed necessary to assess the risk to the public with regard to life and property. These assessments were assigned to and conducted by USACE Louisville and Huntington District personnel under the Federal Emergency Management Agency Region V Mission Assignment COE-LRD-02, for the IDNR.

Limited evaluations were performed on dam embankments and appurtenant works accessible at the time of the site observations. Such features and appurtenant works included the upstream slope, crest, downstream slope, abutments and toes, outlet works, and spillway (when present). The evaluations were limited, with the primary goals being to ensure that each dam had endured the storm and to determine whether any damage
sustained posed an immediate threat to life and property downstream. Secondary goals of the evaluations were to document any visible project deficiencies or disparities between visible project characteristics and conditions, and those noted in IDNR records, and to provide any general recommendations for future and more detailed project evaluations. A total of 127 high-hazard dams were initially identified for immediate, limited visual assessment. Based on further discussions with the IDNR, the list of high hazard dams was reduced to 106 dams. Dam assessments were performed by the 12 pairs of USACE and IDNR personnel within a period of 2.5 days beginning on Thursday 12 June 2008; the levee surveillance mission discussed in this paper began immediately after this mission.

**DAM RECONNAISSANCE OBSERVATIONS**

All privately-owned, high-hazard dams in the affected area south of Indianapolis were inspected to assess damage that could pose an immediate threat to their structural integrity or significantly jeopardize their effectiveness for subsequent storm events. The primary failure modes of concern included overtopping, seepage-related problems, slope-instability, and spillway-related erosion. Maintenance items such as clearing limits, obstructions in spillway, etc. were documented but were not the primary focus of this reconnaissance. Many of the dams were located on remote areas of private property and would have been very difficult, if not impossible to locate using conventional maps. The use of GPS units and GIS coordinates provided by the IDNR provided a very efficient method to locate the remote dams. Along with facilitating successful mission completion, GPS allowed the mission to be completed within a short amount of time.

**Spillway Hydrologic Deficiencies**

Observed outlet control structures and systems were observed to generally be undersized and inadequate to pass flows greater than those associated with routine rainfall intensity. Some projects had no controlled outlet structure which required that all flow pass through the emergency spillway. The undersized spillways (when present) frequently lead to either dam overtopping or excessive spillway velocities that resulted in significant erosion. Considering the amount of precipitation that occurred in much of central and south Indiana, overtopping occurred on a somewhat relatively small percentage of these dams. This was due in large part to the erratic nature of this storm and the wide variability of rainfall intensity over just a few miles. These dams generally had small watersheds on the order of acres and not square miles. The dams that overtopped exhibited various degrees of erosion on the downstream embankment slope, with the amount of erosion related to the size of the drainage area and associated duration that overtopping occurred. Princess East Lake Dam, in Johnson County, exhibited the most downstream erosion of the dams assessed, with erosion features up to 10 feet deep observed. A general view of the downstream slope of the dam is included in Figure 2A, and a close up view of the overtopping erosion is shown in Figure 2B. Note that approximately half of the crest width had eroded by the time the pool had subsided to below the crest. Observers stated that the overtopping lasted for approximately two hours. Upper Peoga Lake Dam, also located in Johnson County, exhibited only a minor amount of erosion directly resulting from overtopping flow. However, as seen in Figure
2C, a large displacement of the downstream embankment face occurred; this was assumed to likely be the result of elevated pore pressures during the event. No breaches were observed on any of the overtopped dams observed by the geotechnical team. As Figure 2. Dam reconnaissance observations during June 2008 included: (A and B) Overtopping erosion of Princess East Lake Dam; (C) Overtopping erosion and embankment slope failure of Upper Peoga Lake Dam; (D) Left abutment erosion of Upper Peoga Lake Dam due to spillway flow; (E) Spillway erosion of Lamb Lake Dam; and (F) Spillway erosion resulting in breach of Earlham Lake Dam.
mentioned, this is likely due to their relatively small drainage areas and short rainfall duration, which contributed to only short durations of overtopping.

**Spillway Geologic Deficiencies**

Most spillways observed during the dam reconnaissance mission were improperly located such that flows ran along the embankment/abutment contact making it susceptible to erosion. At some of the dams observed, excessive spillway velocities caused erosion of both abutment and embankment materials. Examples of such erosion were observed at Upper Peoga Lake Dam (Figure 2D) and Lamb Lake Dam (Figure 2E). These photographs are representative of the close proximity of spillway to embankment on most dams inspected during this event. At Upper Peoga Lake Dam, the embankment was severely eroded by spillway flows along the abutment contact. Downcutting was prevented by bedrock along the abutment (not visible in the photo). Failures were not caused by the erosion at these projects; however, this is primarily due to the short rainfall duration and small drainage areas that shortened the period of increased spillway flow.

Most spillways at observed projects were constructed on bedrock or used a concrete control section to prevent breaching due to erosion. However, a small number of spillways included no erosion control features and had extensive erosion damage. The only breach observed by the authors during inspections occurred at Earlham Lake Dam in Johnson County, and was due to spillway erosion (Figure 2F). This project contained a larger drainage area than most of the observed dams and it did not experience spillway flow frequently due to the presence of a functioning outlet conduit through the embankment. Generally, outlet structures at dams were comprised of corrugated metal pipes through the embankments that were set at normal static pool and were not sufficient to pass flows from low frequency storms such as the June 2008 event.

**LEVEE RECONNAISSANCE BACKGROUND**

Figures 3A and 3B are satellite images which illustrate the extent and severity of flooding along the Wabash and White Rivers during June 2008. The most severe flooding occurred in the lower reaches of these rivers, near the confluence with the Ohio River. The flood frequency for the June 2008 event along the Wabash River at Vincennes was approximately equal to a 10-year event based upon stage and discharge. This site is located upstream of the White River’s confluence with the Wabash River. For comparison purposes, the frequency of the Wabash River downstream of the White River at Mt. Carmel was about a 30-year event. Spencer, located about 13 miles northwest of Bloomington, recorded 9.3 inches of rainfall in a 12 hour period. This rainfall exceeded the estimated 1,000-year rainfall event by 1 inch. Other gauges within the watershed recorded rainfall totals equaling estimated 100 to 200 year events. Previous peak flows within the affected area were in March 1913 and in November 1993. As mentioned above, regional rainfall intensity during the event is shown in Figure 1B.
Figure 3. Satellite views of Knox and Davies counties in southwest Indiana: (A) taken before the June 2008 Midwest Flood; (B) taken on June 11, 2008; and (C) taken on June 11, 2008 with levee systems indicated by red lines. In these images, which were provided by Purdue, USGS, and NASA, the rivers (which are also labeled in C) are indicated by blue and black colors.
LEVEE RECONNAISSANCE OBSERVATIONS

Levees along the lower reaches of the Wabash and White Rivers are shown in Figure 3C. These levees primarily protect agricultural areas with some residential farm structures also included within the protection. The majority of these levees were constructed by non-federal entities while some were constructed by USACE and then transferred to local sponsors. In either case, projects are operated and maintained by non-federal sponsors.

Geotechnical Deficiencies

Common practice during the time of construction for inspected levees was to build using borrow material from immediately riverward of the alignment using dragline equipment. The materials comprising the levees were likely not placed in an engineered manner with controlled lift thicknesses, compaction and moisture conditioning. Also, these levees were generally constructed of the best material that can be found in the vicinity and attention was likely not always paid to zoning of materials to ensure the best performance with regard to seepage. Nonetheless, embankment through-seepage problems were not apparent at any of the projects during inspections. Excessive under-seepage (with sand boils) was however observed over extensive areas at most of the projects inspected. Even areas that did not generate serious seepage stability concerns posed operational challenges in that flows to pump stations became large. These areas appeared as low areas that held surface runoff, but visual observations and local levee board members indicated standing water was generated from under-seepage. During inspection of levees, the authors did not have access to any subsurface data, and instrumentation did not exist.

Observed boils varied widely in number, lateral extent, and severity. Some boils, such as those shown in Figures 4A and 4B were rather large in vertical and lateral extent and were emitting large flows. Many small boils were noted sporadically throughout all of the observed projects. Some of these concentrated seeps produced significant amounts of seepage (>=100 gpm) with often tall (>= 1 ft) sand cones. The boil in Figure 4A was observed at Gill Township Levee approximately 30 feet landward to the toe of the embankment. As observed, the cone of this boil was approximately 4 feet in diameter and the boil was actively producing a considerable amount of seepage; however, during the time of inspection the boil was not moving any additional foundation soil. This type of boil was common throughout the inspected areas and for this inspection the recommendation was to continue to monitor it for production of material or increased quantity of seepage. The boil in Figure 4B was a more problematic one observed at England Pond Levee. As observed, the dimensions of this boil were comparable to the one at Gill Township; however, this one was producing material and warranted closer and more frequent inspection. The fact that this boil was located a few hundred feet downstream of the levee toe, with no signs of distress at the toe, suggested the presence of a landward alluvial blanket with potentially adverse conditions still present at the toe.

At Niblack Levee, pervasive areas containing numerous boils were observed, such as the area as shown in Figure 4C. Most of the observed boils had discharged soil and built cones on the ground surface, but these particular boils were located on sloping ground
Figure 4. Representative conditions observed during June 2008 levee surveillance: (A, B, and C) Sand boils and foundation erosion at Gill Township, England Pond, and Niblack Levees; (D) Sand boil at England Pond Levee toe creating a large delta of foundation material; (E) Sand bag “ring” placed around boil exit at England Pond Levee to slow erosion; and (F) Levee breach at (Illinois) Russell & Allison Levee.
and were continuing to discharge and remove soil without creating a cone to assist in arresting the continuation of piping. It was estimated based on approximate distances and material depth that the two boils in the figure may have removed up to 30 cubic yards of foundation material prior to placement of the sandbags shown in the photograph. The sandbags served the purpose of increasing the head just enough to slow velocities such that foundation material was not being removed. Subsurface data were not available during the time of any inspections; however, conditions observed for one of the boils indicated about a two foot deep hole approximately 5 inches in diameter in a surficial clay blanket; a void was detected in the underlying sand that turned back toward the levee. Since such a large quantity of material had been removed without any surface expression, such as sinkholes or depressions, it was anticipated that the newly formed pipes would continue a backward propagation towards the pool until reaching a more erosion-resistant material in the foundation, and then find a new seepage piping path, in essence creating what appears to look like a braided river channel in plan view of removed material. This concept was confirmed by one of the local sponsors who had excavated and explored one of the areas of heavy seepage at a project (subsequent to a prior flood event) to reveal not just one pipe that had continued to enlarge, but multiple small pipes underlying the clay “roof” material.

Seepage problems at or near levee toes were problematic at a number of projects for many reasons. Many of the concentrated seeps were difficult to find and monitor due to dense vegetation present at the levee toe. The soils discharged from these boils also tended to move away from the seepage exit point due to sloping ground, creating a “delta” of sand landward of the levee. The delta of removed material shown in Figure 4D was estimated to have a radius of approximately 40 feet with material up to a foot deep at the location of seepage exit. At these types of locations, movement of eroded soil did not aid in reducing piping over time, so sand bags were employed as shown in Figure 4E in attempt to help reduce gradients and resulting foundation erosion. General types of seepage remedies (e.g. potential cutoff/control measures) were discussed with local levee board members in order to provide some general information on available alternatives for seepage remediation. Given the potential for seepage conditions to worsen with each event and evidence of material movement, all reaches of levees with heavy seepage and boils were recommended to be thoroughly investigated and remediated to ensure future stability. The above-described seepage instability at Niblack and England Pond Levees was considered severe enough to warrant the provision of precautionary notifications for downstream evacuation during the event.

**Hydrologic Deficiencies**

Several levees throughout the affected area were hydrologically deficient for the June 2008 event and were overtopped as a result. Ambraw Levee in Lawrence County, Illinois on the left bank of the Embarras River was constructed to withstand a 10-year flood event with 3 feet of freeboard. The levee protects approximately 33,000 acres of cropland, farm homes, several small business establishments, an airport, and considerable mileage of improved roads. This levee reportedly was overtopped in the middle of the night by only a few inches and subsequently breached. The levee was inspected hourly during the
incident, and overtopping and breach occurred between inspections. Overtopping was observed to have occurred at certain locations, while at (at least) one other location, such as the Russell & Allison Levee just across the river from Vincennes, Indiana (in Illinois), breach appeared to have occurred without overtopping (Figure 4F) based on visual reconnaissance and local levee board members who had been monitoring the levee.

**Maintenance Deficiencies and Operational Issues**

Levees within in the affected area were up to 40 miles in length and heavily vegetated with grass and weeds (Figure 5A). Often the heavily vegetated areas which were not able to be inspected were landward topographically low areas (areas where seepage concerns may often be the highest). Local sponsors of federal levees kept projects generally free of trees and other woody vegetation, but grass and weeds were sometimes very tall and thick which hindered embankment monitoring ability. As this flood event occurred prior to scheduled mowing, the inspection of certain levees was somewhat restricted. However, since these levees protected mostly farmland, areas landward of levees were usually readily inspect-able (Figure 4C) at this particular time in the growing season while crops (e.g. corn and wheat) were still very small. Another challenge with levees noted during inspections was burrows; this is generally a continual maintenance issue that is addressed by periodically exterminating rodents and backfilling burrows.

The topography of western Indiana is generally flat and composed of large fields, with a small number of drainage ditches. Many of these ditches do not convey water to exit points at pump stations, but only store water until it evaporates or seeps into the in situ soils. These ditches were overflowing from seepage and storm runoff and flooding adjacent crops. Some farmers were pumping these areas to help limit potential crop losses using portable tractor-driven pumps such as the one shown in Figure 5B. Serious seepage-related issues can result from this activity. First, the water stored in the landside ditches helps to reduce the differential head, thereby reducing seepage gradients and uplift pressures at the landward toe. Pumping of these areas can initiate or exacerbate seepage problems. Pumped water also is generally pumped over the line of protection using portable hoses laid over the levee crest. Pumped water exits these hoses at high velocity, and can erode embankment soils unless adequate protection is provided. Figure 5C shows the use of tarpaulins to effectively provide such protection. These concepts were discussed with local levee board members, and recommendations were provided. At Breevort levee, one of the locations where pumping of landward surface water had been occurring, it was also noted that the levee crest was occasionally very irregular and the elevation varied by more than an anticipated amount throughout its length (Figure 5D). Such undulations (typically resulting from initial construction approaches and subsequent settlement) were noted during inspections with crest surveying recommended.

Irrigation and drainage ditches are often constructed landward of levees without consideration for their potential impacts to project stability. At Niblack Levee, as shown in Figure 5E, a large (about 6 feet deep) ditch was excavated for a large distance (> 1 mile) along the levee toe. Even though such ditches are generally full of water during flooding, they greatly increase the potential for instability (e.g. piping) at the levee toe.
Figure 5. Additional representative conditions observed during June 2008 levee surveillance: (A) Heavy vegetation near the landward toe of England Pond Levee; (B and C) Localized pumping of ponded water and discharge over Breevort Levee; (D) A low crest elevation area, and dense vegetation inhibiting inspection of Breevort Levee; and (E and F) Agricultural toe ditch contributing to seepage problems at Niblack Levee.
Numerous boils and related sloughs (due to the excessive removal of foundation material) were observed in and along the banks of this ditch (Figure 5F). Such ditches, where present within close proximity to levees, should be evaluated and back-filled in if it is determined that their location and geometry is problematic.

CLOSING REMARKS

The record rainfall that occurred in the Midwest in June 2008 gave the U.S. Army Corps of Engineers a unique opportunity to observe the performance of privately owned dams along with several levee systems under extreme (greater than design) loads. Provided that many of the dams observed during this event were not designed or built to modern day design criteria, it could be argued, despite observed deficiencies, that the inspected dams as a whole performed better than may have been expected. Of the more than 100 dams assessed, thirteen dams had been overtopped; however, no dams experienced a loss of crest elevation and pool due to this erosion. Spillway erosion was the most common and problematic deficiency observed across the inspected inventory. Many dams had sustained damage from such erosion, but only one dam had sufficient spillway erosion such that it could no longer contain its normal pool. Seven of the inspected dams were judged to be in such condition that they require immediate remedial action.

Similar to observed dams, and despite the observed deficiencies, it was observed that most levees inspected along the Wabash and White Rivers generally performed better than may have been anticipated given their lack of seepage cutoff/control features and apparent lack of construction in accordance with modern day design procedures. No slope failures were observed on the protected side of levees, and observed pump stations and appurtenant works appeared to function as designed. The primary concern associated with observed levees was under-seepage instability due to excessive gradients through stratified foundation soils. Where such instability was observed, follow-up remedial investigation, design, and construction of appropriate measures were recommended and are currently underway. Additional concerns associated with observed levees were the lack of subsurface information and instrumentation, the frequent presence of crest elevation undulations, and the frequent presence of dense vegetation.

The success and efficiency of the dam and levee reconnaissance missions were in large part due to effective communications between office and field personnel, readily available GIS data on dam locations and characteristics, the availability of GPS units for field personnel, and having experienced teams of both State employees/local sponsors and geotechnical professionals standing ready to deploy when called upon. Observed conditions and reconnaissance challenges during the June 2008 Midwest Flood demonstrate the need for proactively recognizing and addressing potential geotechnical-related risks associated with many of the Nation’s high hazard dams and levees.