GEOTECHNICAL EXTREME EVENTS RECONNAISSANCE (GEER) ASSOCIATION

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THE GEOTECHNICAL ASPECTS OF THE CENTRAL TEXAS FLOODS OF MAY 23-25, 2015

Report of the NSF Sponsored GEER Association Team

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GEER Association Report No. GEER-039

Version 1: June 12, 2015

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Acknowledgements:
We would like to extend special thanks to Greg Creacy, Jamie Hackett, David Riskind, and Robert Trudeau of the Texas Parks and Wildlife Department (TPWD) for providing access to the Bastrop State Park Dam, eye witness accounts, and infrastructure reports for the dam. Thanks also go to Raymond Slade, retired hydrologist from the USGS, for providing information on historical rainfall in Texas, Dr. Trevor Hyrnyk (University of Texas) for providing input regarding the interpretation of the bridge failures, and Larson Snyder, Elisson Pereira da Silva, and Ivan Coutinho Martins (students at the University of Texas) for performing the grain size analysis and Atterberg limits tests.

Introduction

During Memorial Day Weekend of 2015 (May 23-25) two significant rainfall events occurred in Central Texas, in and around the city of Austin. This area has been called "Flash Flood Alley" (http://floodsafety.com/texas/regional_info/regional_info/austin_zone.htm#a) due to the history of significant and intense rainfall events that have occurred here. The Balcones Escarpment, which separates the Texas Hill Country/Edwards Plateau to the west from the Gulf Coastal Plain to the east (Figure 1), contributes to the occurrence of large storms because moisture-filled air from the Gulf of Mexico cools and condenses as it rises up the escarpment. Some of highest rainfall intensities ever recorded have occurred in Central Texas, including a 1921 storm in Thrall, Texas that produced 32 inches of rain in 12 hours (Slade 1986).

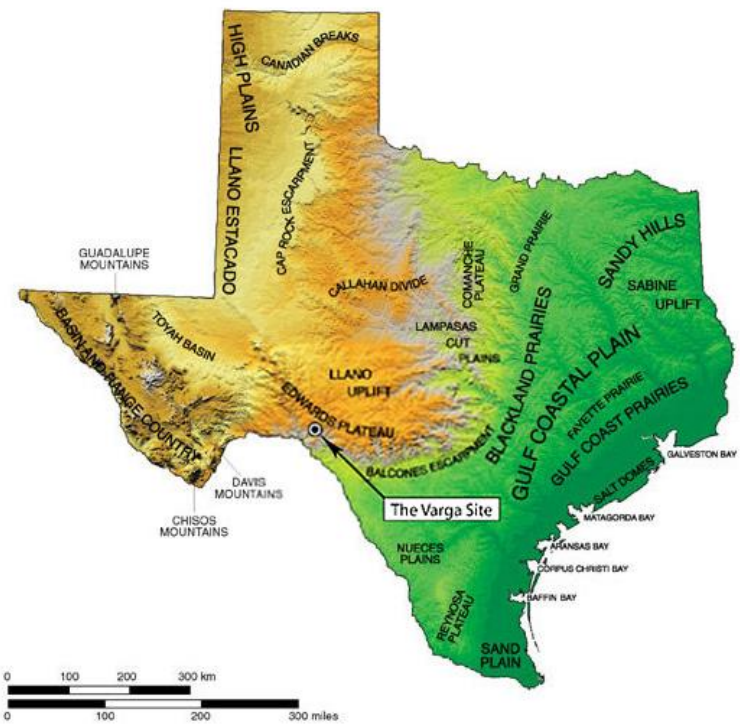


Figure 1. Physiographic map of Texas (http://www.texasbeyondhistory.net/varga/images/physio-map.html)

During Memorial Day Weekend of 2015, the first rainfall event began about 4 pm on May 23 and in four hours dropped about 8 to 10 inches of rain in Blanco County near the head of the Blanco River. This rain caused a significant rise in the Blanco River that caused damage along the river in Blanco, Fischer, Wimberley, and San Marcos. The river flooding collapsed and damaged several bridges along the Blanco River, damaged and swept away many homes, and killed twelve people.

The second rainfall event began around 4 pm on May 25, dropping about 4 to 5 inches of rain in Travis and Bastrop Counties in about 2 hours. This rain caused significant flooding along creeks in the city of Austin and caused the failure of the earth dam at Bastrop State Park Lake.

The reconnaissance team visited the dam at Bastrop State Park Lake on May 27 and 29, and bridges along the Blanco River on May 29 (Figure 2). This report summarizes the observations from the sites visited.

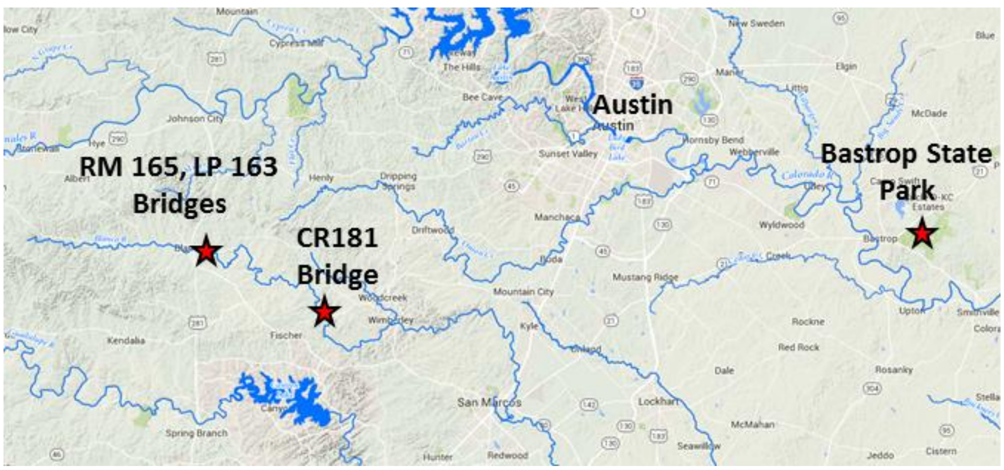


Figure 2. Sites visited during reconnaissance of the 2015 Central Texas Floods. (Map from http://hydromet.lcra.org/)

Bridge Performance along the Blanco River

The rainfall event on the evening of May 23, 2015 dropped 8 to 10 inches of rain west of the town of Blanco, TX. The river gauge at Wimberley, TX, located approximately 20 miles east of Blanco (Figure 2), recorded a river height of 40.2 ft as compared to the flood stage of 26 ft. The largest recorded height at this gauge before this event was 33.3 ft in 1921 (http://water.weather.gov/ahps2/hydrograph.php?wfo=ewx&gage=wmbt2). It is possible that the river crested even higher than 40.2 ft because the gauge was damaged. The river level between Blanco and Wimberley is unknown. The GEER Reconnaissance team visited three bridges along the Blanco River on May 29, 2015.

Fischer Store Road/CR 181 Bridge

The county-maintained Fischer Store Road/CR 181 Bridge crosses the Blanco River approximately 5 miles northeast of Fischer, TX (Figure 2, 30.000530°N, -98.200038°W). The entire five-span bridge superstructure was displaced off of the supports, and portions of the superstructure settled on the river banks just downstream from the supports (Figure 3). The bridge was supported by two wall piers in the middle of the river channel, and two cap and column piers located on the embankments along the river channel. The superstructure rested on elastomeric bearing pads, many of which were washed away during the flood. Lateral forces in the superstructure were transferred to the substructure via shear pins, located only at the exterior girder supports. Significant plastic deformation of the shear pins was observed. There was no apparent mechanism provided to accommodate uplift force transfer between the super- and sub-structures.

The wall piers appeared to have minimal damage. Damage was primarily observed in the cover concrete along the downstream edge of the pier cap (Figure 4) and is believed to have occurred as the girders were being pulled off the supports. Both cap and column piers were severely damaged, with the most severe damage being in the western bent. Hinging and complete section failures were observed at the construction joints between the columns and the bent cap, as indicated by the smooth surface in the failed cross-section (Figure 5a). The longitudinal bars in the column partially pulled out of the bent cap. In the downstream column in the western bent, several of the longitudinal bars fractured. The base of the columns/top of drilled shafts appeared to have rotated rigidly due to soil failure (Figure 5b). Soil was removed near the top of the foundation, and no signs of hinging were observed in the few feet of the drilled shaft just below the soil surface.

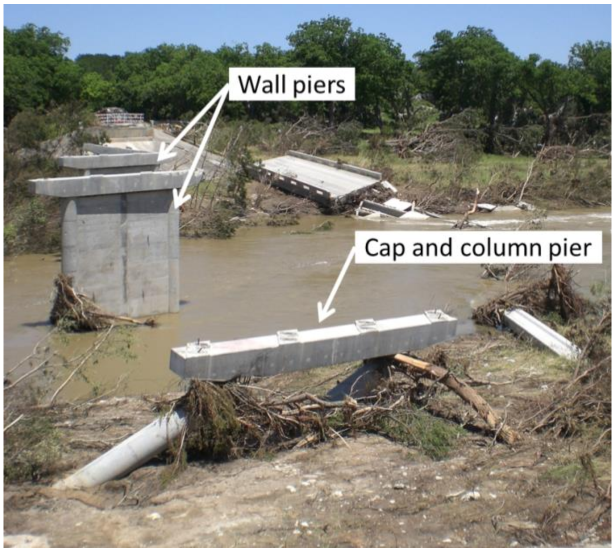


Figure 3. Fischer Store Road/CR181 Bridge (view from west abutment)

Figure 4. Damage to wall piers

(a) (b)

Figure 5. Damage to western bent: (a) hinging at top of upstream column and (b) rigid body rotation at foundation

RM 165 Bridge

The RM 165 Bridge over the Blanco River is located approximately 1.5 miles east of Blanco, TX and is approximately 25 river-miles upstream of the Fischer Store Road/CR181 Bridge (Figure 2, 30.090978°N, -98.401736°W). The bridge, built in 1994, was very heavily skewed as shown in Figure 6 and had a curve in the western portion of the bridge. The superstructure was supported by four wall piers on the eastern portion of the bridge, aligned with the channel flow direction, and one four-column bent near the west abutment. Similar to the Fischer Store Road Bridge, the lateral forces in the superstructure appeared to have been transferred to the substructure via shear pins at the exterior girder supports.

During the flooding, the superstructure along the eastern portion of the bridge was carried downstream a short distance and the three wall piers under this section of the bridge collapsed (Figure 7). One of the wall piers was resting on the collapsed superstructure (Figure 7), so it appears that the superstructure collapsed before the piers. The failure at the eastern-most wall pier was observed to be net section failure along the base of the pier (Figure 8a). The piers were placed on drilled shaft constructed directly in limestone. The web regions of the walls did not appear to have any reinforcement embedded in the limestone, whereas longitudinal bars from the drilled shafts were embedded in the pier columns above. All of the bars passing through the column-to-pile interface were fractured. As shown in Figure 8b, the column longitudinal bars appear to have been spliced just above the foundation interface, which may have contributed to the failure of the critical section at the foundation interface. Although the other collapsed wall piers were still under water at the time of observation, they are believed to have failed in a similar manner. The two westernmost-bridge spans did not collapse but the girders comprising these spans were noticeably shifted from their original support locations (Figure 9). The rotations of these girders suggests that the shifting was associated with the washed out portion of the superstructure pulling the remaining portion of the superstructure as it traveled downstream.

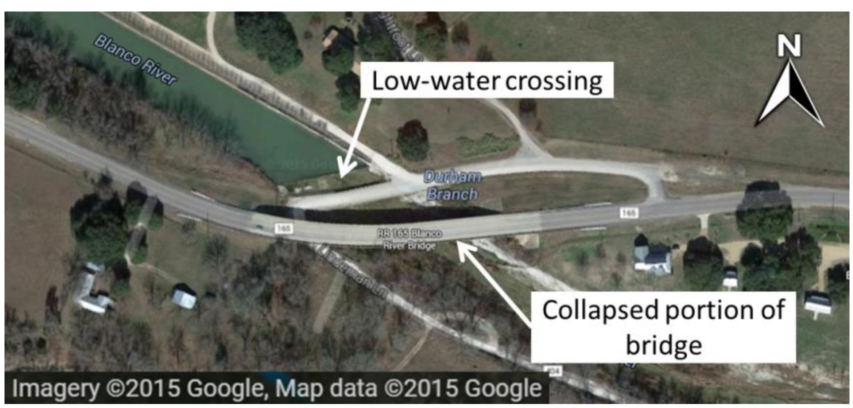


Figure 6. Layout of RM 165 Bridge (Figure courtesy of Google Maps)

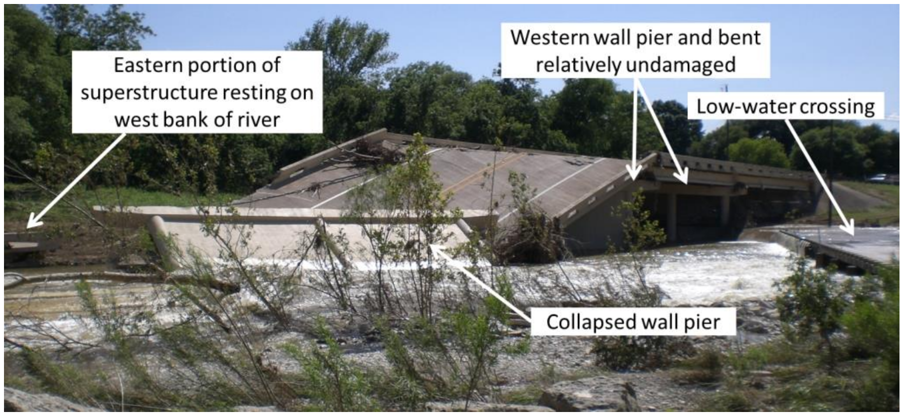
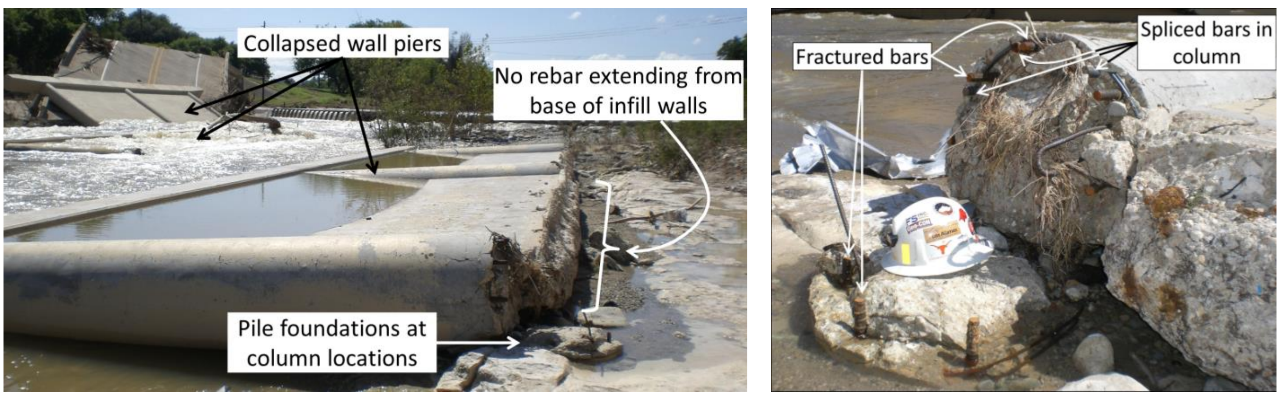


Figure 7. View of RM 165 Bridge from the east



(a) (b)

Figure 8. Collapsed wall piers. (a) section failure at base and (b) splice at base of pier columns

Figure 9. Shifting of girders at west abutment

LP 163 Bridge

The LP 163 Bridge, built in 2002, was a little over 1 river-mile upstream from the RM 165 Bridge (Figure 2, 30.096229°N, -98.418153°W). The bridge was supported by three wall piers in the river channel (Figure 10). According to witnesses on site at the time of flooding, the bridge was completely overtopped during the flood; however, no significant post-event damage was observed.

Figure 10. LP 165 Bridge relatively undamaged

General Observations

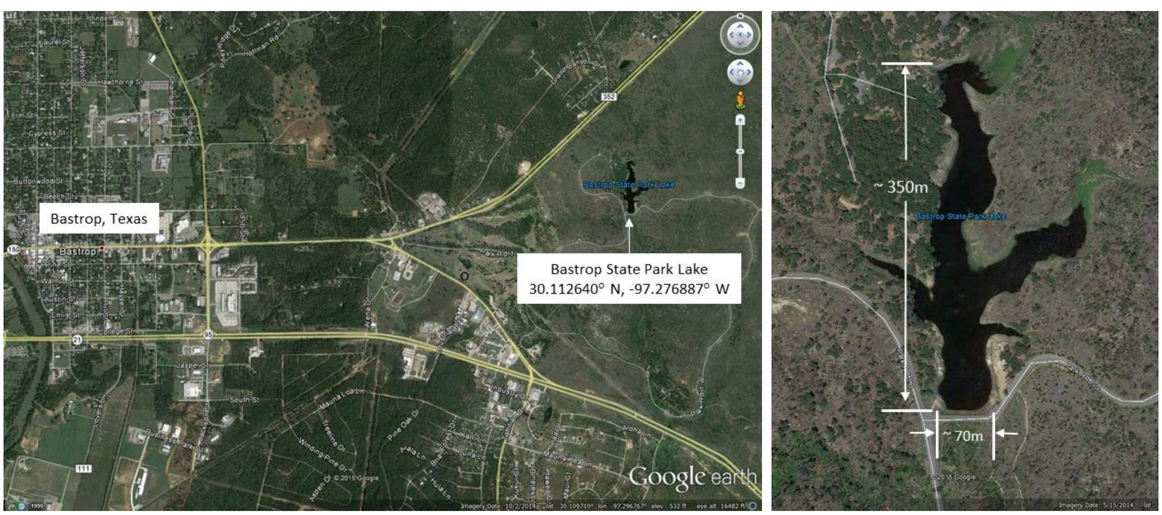
Reconnaissance visits to the three bridges along the Blanco River allow for some general observations to be made, as described below.

- The along-flow lateral restraint provided by the solid web regions of the wall piers appears to have improved performance during flooding compared to cap and column bents for the cases where relatively uniform river flow was parallel to the wall direction (i.e., center sections of Fischer Store Road/CR 181 Bridge, LP 163 Bridge). However, lateral loads perpendicular to the wall (i.e., in the out-of-plane direction) may develop under non-idealized flow conditions and may have contributed to wall failure/collapse at the RM 165 Bridge.
- The locations of observed net section failures in the reinforced concrete piers (at the tops of columns in the Fischer Store Road Bridge and at the base of the walls in the LP 165 Bridge) appeared to coincide with locations of construction joints and/or lap splices.
- Neither of the collapsed bridges appeared to have had any mechanism for transferring uplift forces from the superstructure to the substructure and lateral load transfer was provided only by relatively small shear pins in the exterior girders. Both of these issues may have contributed to the superstructure being washed away. Further information and design drawings are necessary to identify the uplift and lateral force transfer mechanisms used in the LP 163 Bridge, which performed well during the floods.

Dam Failure at Bastrop State Park Lake

Bastrop State Park Lake is located approximately 2 miles east of Bastrop, Texas (Figure 11, 30.112640°N, -97.276887°W). The lake was formed from a man-made earth dam that was originally constructed across Copperas Creek in 1913-1914 to create a fishing lake. The dam subsequently received improvements in 1934 as part of the Civilian Conservation Corps public works program (Beck 2015). The dam was relatively small, 7.3 m (24 ft) high and impounding a lake with a maximum capacity of 110 acre-feet when full (TCEQ 2005). The bedrock beneath the dam is mapped as Carrizo Sand (Collins 2000), which is described as gray sandstone with some silty clay that weathers to yellowish/reddish brown due to some iron content (http://txpub.usgs.gov/DSS/texasgeology). There are also areas of Pleistocene river terrace deposits that consist of predominantly gravel with some silty clay.

The lake was approximately 70 m wide at the dam and approximately 350 m long (Figure 11). The dam was outfitted with a small culvert-type spillway that runs approximately northeast-to-southwest underneath the existing road (Figure 12). While small, this culvert-type spillway had historically been sufficient to keep the water in the lake from over-topping the dam. Exceptions to this occurred in 1992 (TCEQ 2005) and January 2012, when water in the lake flowed over a low spot on the east abutment (Figure 12). Although not designed as a spillway, this low spot is referred to as the emergency spillway in a Dam Safety Report by TCEQ (2005). The low spot is approximately 0.64 m above the top of the culvert-type spillway and 0.29 m below the crest of the dam (the crest of the dam was inferred by connecting survey points from the remaining segments of the dam after the failure). While the flow across the low spot on the east abutment caused little-to-no erosion/damage to the dam in 2012 (personal communication, Greg Creacy, TPWD), flow through the culvert-type spillway was intense, leading to a washout of the second culvert that passes approximately west-to-east under the main approach road (Figure 12), which is well below the downstream toe of the dam.



(a) (b)

Figure 11. (a) Location of Bastrop State Park Lake, (b) approximate size of Bastrop Stake Park Lake (imagery courtesy of Google Earth).

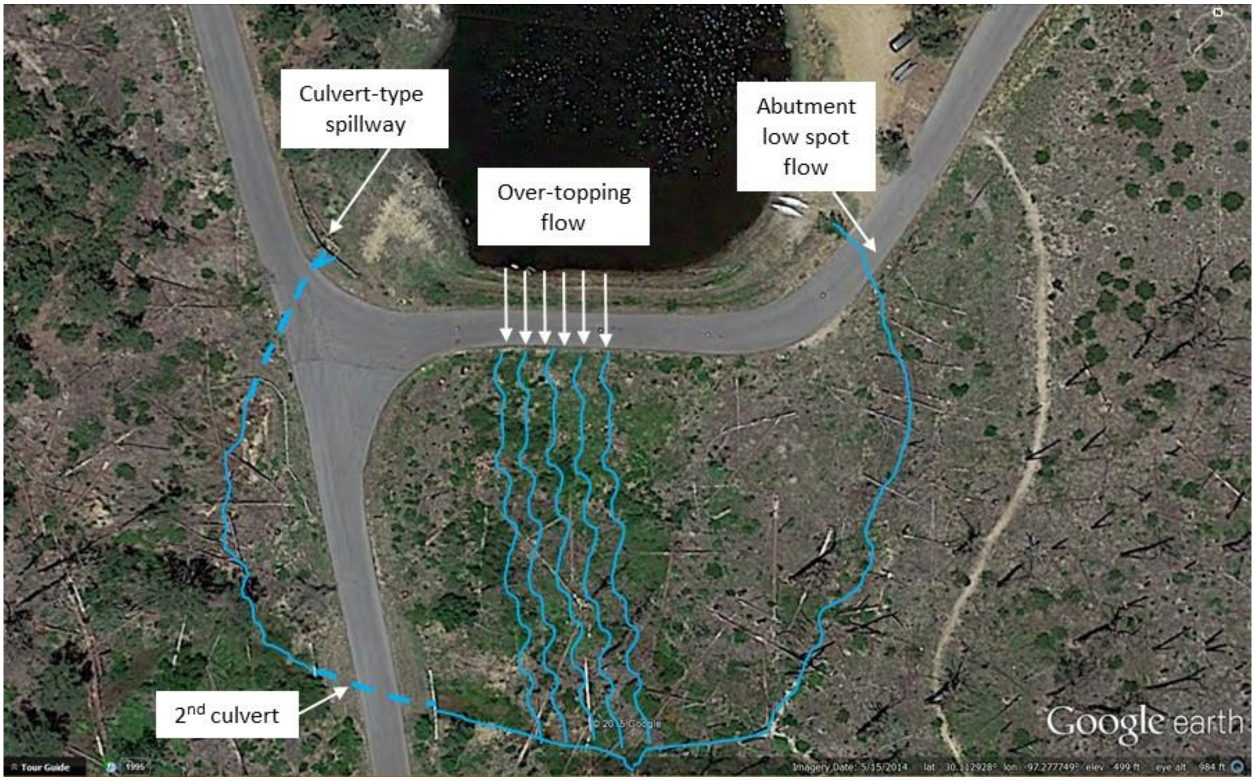


Figure 12. Schematic of the flow conditions at the time of failure (imagery courtesy of Google Earth).

On Monday, May 25, 2015 significant rain began in the Bastrop area at about 5 pm. Between about 5 pm and 6:30 pm, over 4 inches of rain fell in the Bastrop area as inferred from LCRA rain gauges at Lake Bastrop, 2.2 miles north of the dam (4.4 inches of rain measured), and at the Colorado River in Bastrop, 2.5 miles west of the dam (4.6 inches of rain measured). The rain gauge at Bastrop State Park only reports daily rain fall, and measured 4.83 inches on May 25. At approximately 6:30 pm a TPWD employee approached the dam. He noticed water running across the road at the location of the second culvert. He passed through this water in his pickup truck and drove to the top of the dam, where he noticed water from the lake flowing over the crest near the mid-point of the dam. At this time, he reported that a section of the asphalt approximately 5-m long by 3-m wide (approximately 15 ft by 3 ft) had been eroded from the south-side of the road that crossed the crest of the dam (personal communication, Robert Trudeau, TPWD). At this time, he left the dam to warn others of the impending failure. At approximately 6:48 pm, TPWD employee Greg Creacy approached the dam and witnessed the complete overtopping flow and failure shown in the photograph of Figure 13.


Figure 13. Water over-topping the dam at 6:48 PM on May 25, 2015 (photo from Greg Creacy, TPWD).

On Wednesday, May 27 and Friday, May 29 the GEER reconnaissance team visited the dam, collected samples, and performed a topographic survey using a total station. Our observations are summarized below:

1. A section of the dam approximately 35.5 m wide was washed out during the flood. The depth of the failure was approximately 7.1 m (Figures 14 and 15). The three-dimensional geometry of the site on May 29 and a cross-section through the remaining section of dam on the east abutment are shown in Figure 16.
2. The topographic survey indicated that the remaining segments of the dam had an upstream slope of approximately 26 degrees near the crest and 12 degrees closer to the exposed lakebed. The downstream slope was approximately 29 degrees (Figure 17a). Halff Associates (2013) reported that both upstream and downstream faces were 1.7H:1V (30.5°), as inferred from a LIDAR survey performed in 2008.
3. There appeared to be no clear evidence of a clay/fine-grained core. Rather, the dam appeared to be constructed of clayey-sand soils that were only slightly different in color from one another: a slightly more tan material on the upstream slope, and a slightly more red material on the downstream slope (Figure 17b). At first glance, the east abutment appeared to have a third type of dark red soil in the middle of the dam (Figure 17a). However, this dark red soil was determined to have slumped into the core area of the dam from the near-surface material at the time of failure, as it only existed at the surface of the failure scarp.
4. Three bulk soil samples were taken from the east abutment at the approximate locations indicated in Figure 17a. All of these soil samples classified as clayey sand with between

30 and 40% fines and a PI of around 15. These characteristics are similar to those of the native Carrizo Sand found in the area.

5. The culvert-type spillway was small (approximately 1 m x 1 m), but not plugged by debris at the time of our visit (Figure 18). TPWD indicates that that the culvert was not cleared of debris prior to our visit.
6. A significant amount of water clearly flowed over the low spot on the east abutment (Figure 19). This flow had not eroded the native material immediately downstream from the road to a significant degree. However, approximately 70 m downstream from the low spot in the pavement a significant crevasse had opened up and was eroded by the running water (Figure 20). This crevasse apparently first developed during the 2012 flood when the water overtopped the low spot in the abutment (personal communication, Greg Creacy, TPWD). The erosion did not appear to exacerbate the actual dam failure. Rather, it probably served to extend the life of the dam as water overtopped this location first.

Another consideration for this dam failure is the effect of the 2011 Bastrop County Wildfires on the runoff to the lake. The burn severity from the wildfires is shown in Figure 21a. Although the area around the lake was only scorched, much of the runoff zone for Copperas Creek upstream of the lake to the northeast (Figure 21b) was heavily burned (Figure 21a). TPWD employee Greg Creacy noted that the hydrology throughout the park has been affected by the fires and that, anecdotally, it appeared to him that run off to the lake had increased since the fires.

Figure 14. View of dam failure from upstream of the west abutment.

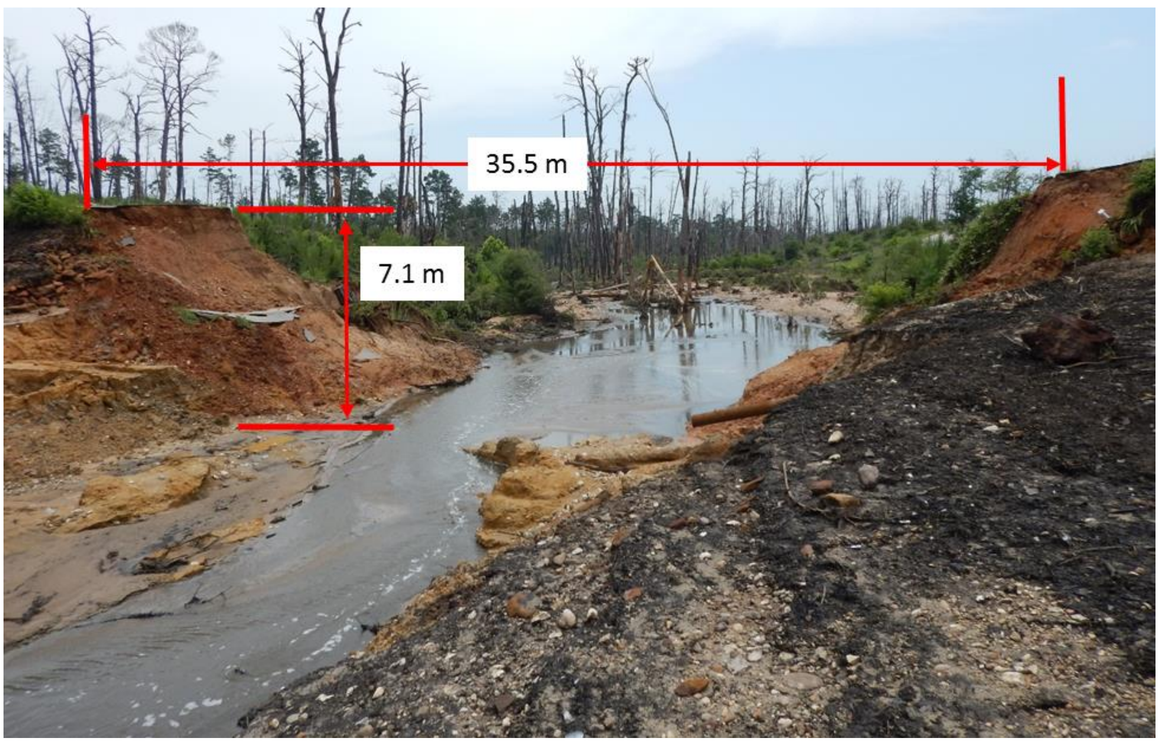
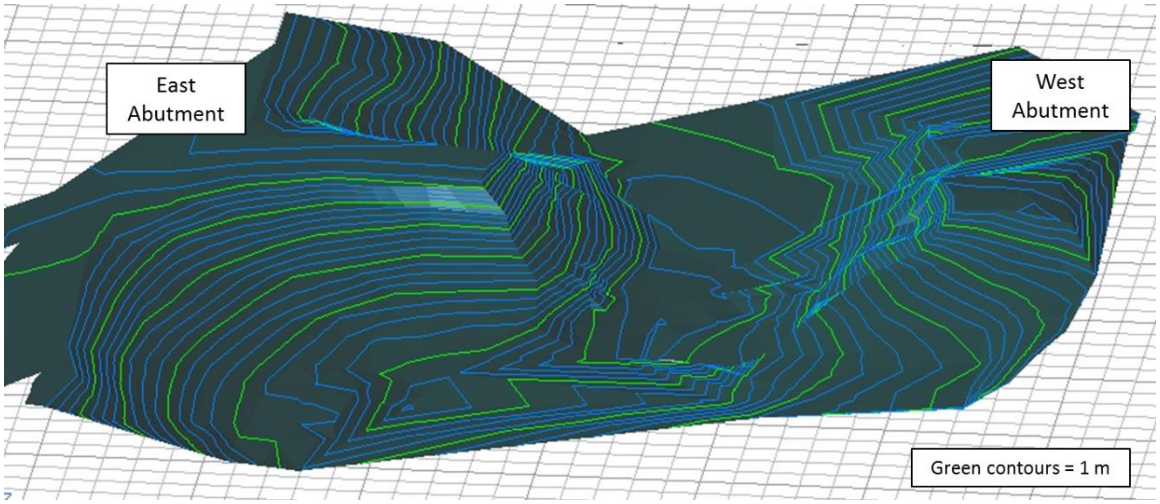
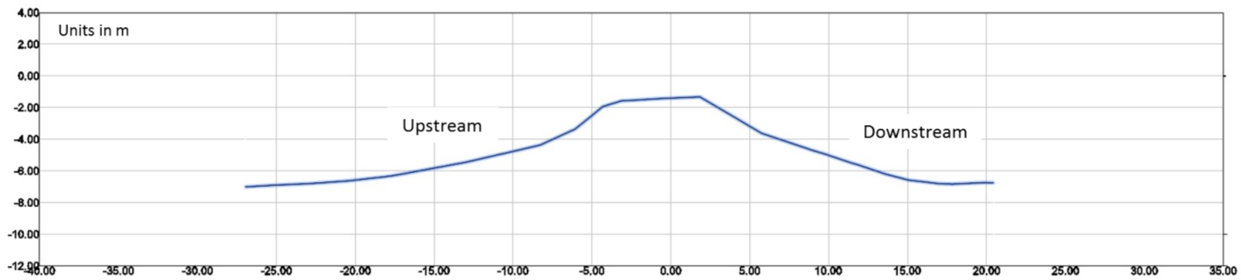


Figure 15. View of dam from upstream in the middle of the former lake.

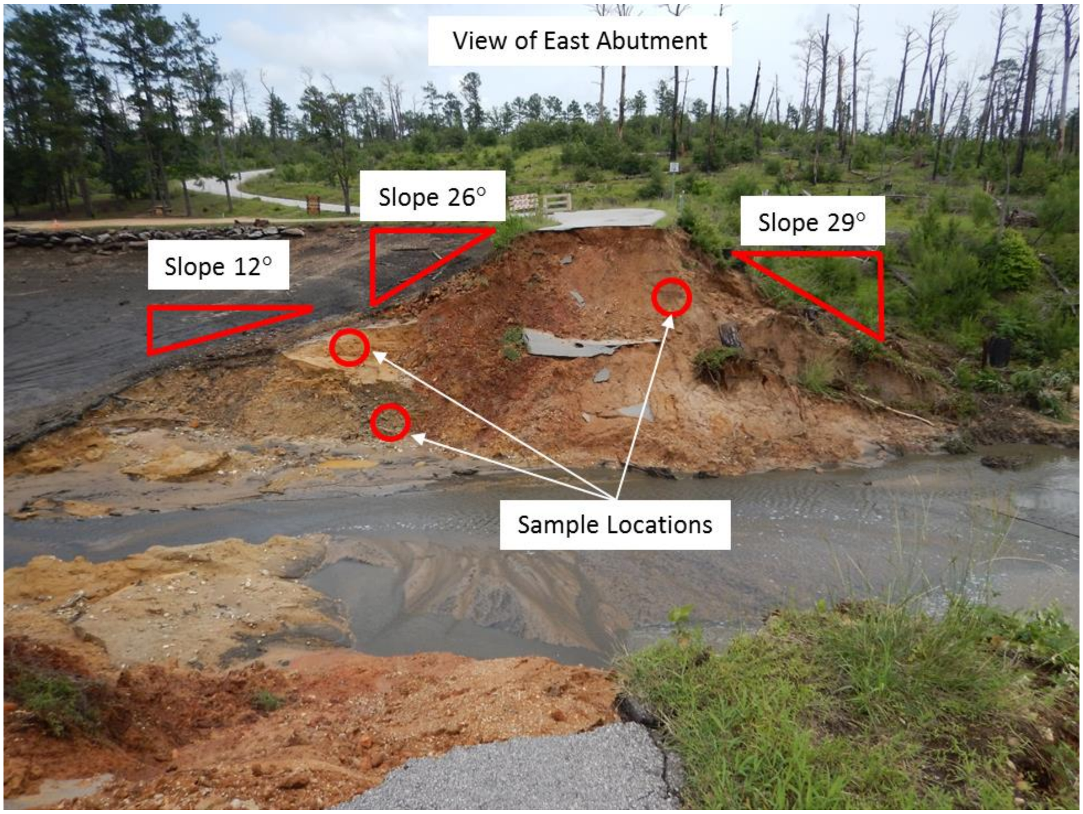


(a)



(b)

Figure 16. (a) 3D geometry of dam site after failure and (b) cross-section through east abutment.



(a)

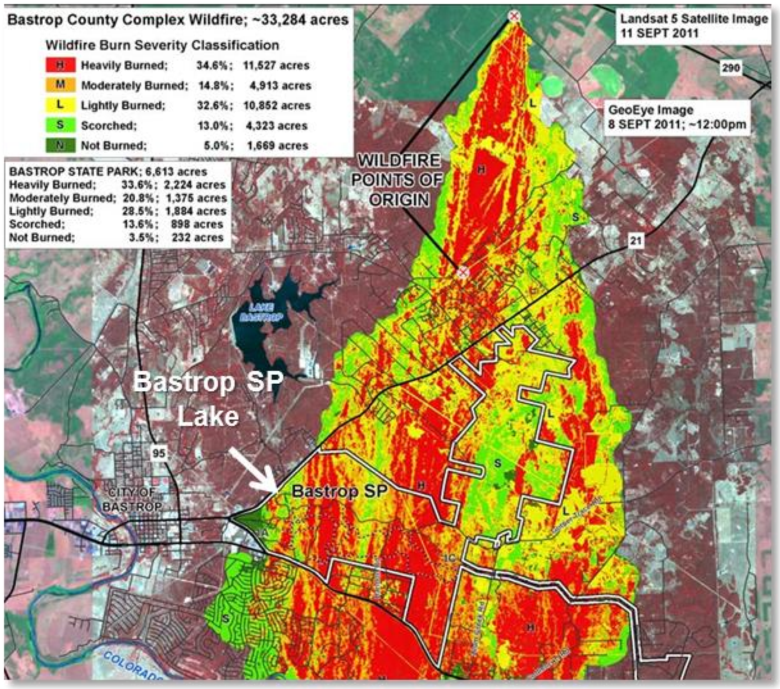
(b)

Figure 17. (a) View of west abutment and (b) view of west abutment.

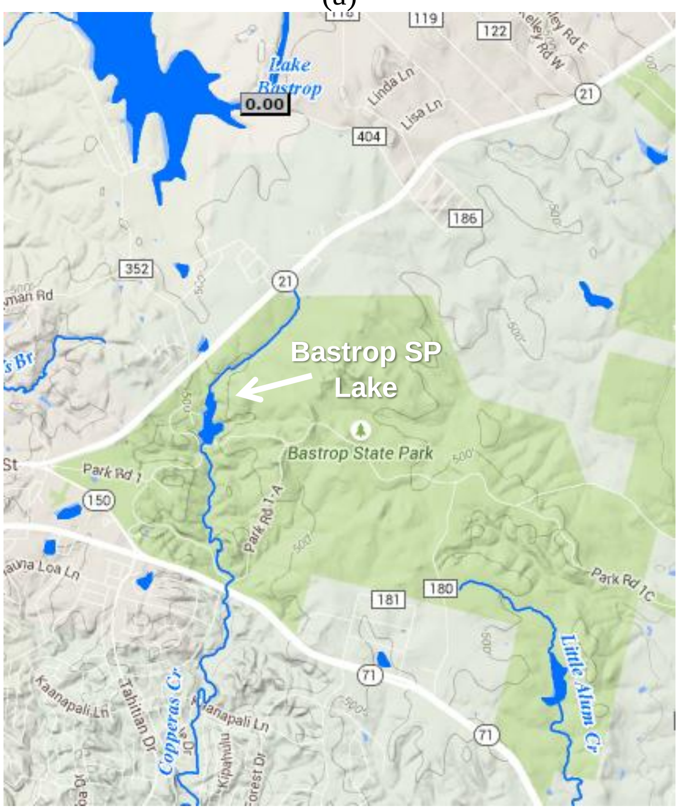
Figure 18. Culvert-type spillway on west abutment

Figure 19. View of erosional channel just downstream from the low spot in the east abutment.


Figure 20. View of erosional crevasse about 70 m downstream from the low spot on the east abutment.



(a)



(b)

Figure 21. (a) Burn severity from 2011 Bastrop County Complex Wildfire (https://tpwd.texas.gov/spdest/findadest/parks/bastrop/fire),
(b) Creek drainage for Copperas Creek and Bastrop State Park Lake (http://hydromet.lcra.org/)

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