SPRING LAKE DAM EMERGENCY STABILIZATION
BASIS OF DESIGN REPORT

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USM17348
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1.0 BACKGROUND

Spring Lake Dam (TX01588) is a small, significant-hazard dam in San Marcos, Texas that forms Spring Lake at the headwaters of the San Marcos River. Severe flooding in October 2015 across Texas led to a major disaster declaration on November 25, 2015 (DR-4245) which included Hays County. Spring Lake Dam was reportedly overtopped by several feet of water during the event, and the overtopping flows continued for more than a week afterward, severely damaging the structure. Texas State University (University) contracted with Freese and Nichols, Inc. (FNI) on May 5, 2017 (PO #4500116639) to perform professional engineering services related to damages caused by the 2015 to Spring Lake Dam, including preliminary and final design for the emergency stabilization project. The University is in the process of applying for a Category B public assistance grant from the Federal Emergency Management Agency (FEMA) to fund the project. This report documents the basis of design for the emergency stabilization project.

The upper San Marcos River is home to unique archeological and biological resources, including eight federally-listed endangered species. In addition, the San Marcos Springs which issue forth upstream of the dam below Spring Lake are among the most prolific springs in Texas. Because of its historical significance, ecological importance, and value to the community of San Marcos, the project has required input from many stakeholders and regulatory authorities.

*Please note that Spring Lake Dam does not currently meet state standards for dam safety and has several outstanding recommendations from TCEQ. The proposed emergency stabilization project documented in this report will not bring the dam into compliance with state dam safety regulations. The project is solely intended to reduce the vulnerability of the structure as an interim measure to protect public safety while a long-term modernization project can be developed by Texas State University.*

1.1 DESCRIPTION OF DAM

Spring Lake Dam (also known as Aquarena Dam) is a rockfill embankment dam in Hays County, Texas. It is located within the City of San Marcos near the intersection of Aquarena Springs Drive and East Sessom Drive (Figure 1.1). The dam was originally constructed around the year 1849 to provide power for a saw and grist mill. Over its lifetime, it has been modified and repaired on numerous occasions. Spring Lake and the surrounding area are now owned by Texas State University and serve as an educational center and park operated by the Meadows Center for Water and the Environment.

The dam is approximately 440 feet long with a maximum height of approximately 9 feet. Two uncontrolled service spillways pass normal flows to the downstream channels, one at each of the left and right abutments. The west spillway on the right side of the dam consists of four weirs with flashboards for adjusting the crest height. Flow from the weirs passes through a concrete chute and plunges into the San Marcos River downstream. Structural repairs to the west spillway were performed in 2001, including repairs to the concrete spillway and addition of a toe drain along a portion of the embankment near the west spillway. The east spillway on the left side of the dam consists of an approximately 40-foot wide
concrete weir. The east spillway channel confluences with the San Marcos River downstream from Spring Lake Dam. A diversion structure and tailrace are located below a restaurant patio (currently the Saltgrass Steakhouse) and are permanently blocked from flow.

![Figure 1.1: Project Location](image)

The dam was initially constructed at the site in 1849 although it has likely been reconstructed at least once since that time. Historical research indicates that the current configuration and general appearance of the dam date to 1909 [2]. Historical descriptions and recent observations suggest the dam is composed primarily of rockfill and cedar cribbing with a clay liner on the upstream slope. Much of the crest and downstream slope is capped with grouted rock riprap and unreinforced concrete. Several large trees are growing along the crest of the dam which may have been originally planted as reinforcement for the rockfill structure [2]. Figure 1.2 shows the assumed as-built section through the embankment.
The following timeline summarizes the known history of the dam’s construction and repairs [2, 4]:

- **1849** Dam constructed by Edward Burleson across the San Marcos River using cedar piles and various earthen materials to provide power for a saw and grist mill.
- **1884** Ice plant and water works constructed on the west end of the dam. Dam repaired/reconstructed to a height of six feet.
- **1904** Dam reported to have a maximum height of 15 feet to provide head for water power turbines owned by various utility companies.
- **1909** Improvements to dam made, including a concrete training wall on the east spillway which still bears an inscription of the date December 9, 1909.
- **1926** Spring Lake property and dam purchased by A.B. Rogers for development of a recreation and tourism venture, including a hotel and golf course.
- **1940** Texas Public Utilities Company turns over hydroelectric operations to Lower Colorado River Authority.
- **1949** Aquarena resort expanded, including glass bottom boat tours and submarine theater.
- **1971** Concrete cutoff wall placed in a trench along embankment centerline in an attempt to mitigate seepage.
- **1994** Dam and surrounding property purchased by Texas State University.
- **1998** Dam and west spillway damaged by severe flooding.
- 2001 Structural repair project completed to address damage caused by 1998 flood.
- 2013, 2015 Severe flooding overtops dam, leading to damage of the embankment.

1.2 EXISTING CONDITIONS

FNI engineers and environmental scientists performed a site visit to Spring Lake Dam on July 6, 2017. The purpose of the visit was to document the flood damage to the embankment and spillways. FNI compared the existing conditions of the dam to previous inspection reports by TCEQ and the University’s previous consultants to estimate damage specifically related to the 2015 flood event. Specific damages are summarized in Figure 1.3 and described below.

1. Embankment Scour
2. East Spillway Scour
3. Seepage
4. Low Areas on Embankment Crest

Figure 1.3: Summary of Flood Damages

1) **Embankment Scour:** Three specific areas along the downstream toe of the embankment have sustained erosion damage from overtopping storm flows. This eroded material serves a critical role in the stability of the embankment.
   a) A small area near the west spillway and toe drain outfall(Figure 1.4)
   b) A large area just east of the concrete headwall structure (Figure 1.5)
   c) A large area near the east spillway (Figure 1.6)
Figure 1.4: Scour at Embankment Toe near Toe Drain Outfall

Figure 1.5: Scour along Embankment Toe near Head Wall Structure
2) **East Spillway Scour:** The slab at the east spillway has been undermined by storm flows (Figure 1.7). The slab is overhanging by several feet in some locations. The unsupported slab is vulnerable to additional erosion that could fail the spillway.

3) **Seepage through Embankment:** Seepage at the dam has worsened since the flood event, indicating erosion damage to the existing clay on the upstream slope. The toe drain outfall is flowing completely full and seepage is exiting along most of the downstream toe of the embankment (Figure 1.8). The amount of seepage observed during the site visit (excluding flow from the toe drain) was approximately 100-500 gallons per minute.
4) **Low Areas along Embankment Crest:** Settlement and/or erosion has created two low spots along the crest of the embankment. The low spots could concentrate flow when the embankment is overtopped and accelerate erosion and scour of the unprotected embankment structure (Figure 1.9).

1.2.1 **Other Deficiencies**

The emergency stabilization project is intended to address damage resulting from the October 2015 flooding and return the structure to its pre-disaster condition. However, with its 160-year history, Spring Lake Dam is beyond the normal design life for a typical dam and does not currently meet state standards for dam safety. The dam is not designed to pass the regulatory design flood safely. The embankment has little freeboard and minimal excess spillway capacity, and high stream flows from storm events frequently overtop and damage the structure. Spring Lake Dam has faced many major flood events which have
resulted in substantial and progressive damage to the embankment and spillways. In addition, the structure predates modern dam design principles and construction techniques. Addressing these deficiencies to bring the dam into compliance with state dam safety rules will require a comprehensive rehabilitation or replacement of the structure which is beyond the scope of the emergency stabilization project.

1.3 DESCRIPTION OF PROPOSED REPAIRS

The proposed repairs to Spring Lake Dam include the following:

- Place rock riprap in the scoured areas of the downstream toe of the embankment.
- Repair the undermining and broken concrete slab on the east spillway.
- Install bentonite/aggregate composite in areas of concentrated seepage on the upstream slope of the dam to reduce seepage volume through the embankment.
- Level the low spots of the embankment crest with installation of dental concrete.

The proposed repairs are shown in Figure 1.10.

![Figure 1.10: Summary of Proposed Repairs](image)

1.4 DESIGN CRITERIA

As mentioned in Section 1.2.1, the stabilization project is intended to address damage resulting from the October 2015 flooding and return the structure to its pre-disaster condition as an emergency protective
measure. The conditions of the federal funding do not allow for permanent improvement or rehabilitation of the pre-disaster condition of the structure. Thus, the design criteria for the stabilization project are limited to the dam’s approximate condition prior to the October 2015 flood event and/or installation of temporary measures to reduce the immediate vulnerability of the structure. Except where noted, the stabilization designs are not based on specific loading conditions or a design storm event but rather returning the dam to its pre-2015 condition. Per 30 TAC Chapter 299 Subchapter C, emergency repairs are exempt from certain requirements from TCEQ, including review and approval of construction plans and specifications.

2.0 HYDRAULIC DESIGN

2.1 CFD MODEL SETUP

As mentioned above, the emergency stabilization project is solely intended to reduce the vulnerability of the structure as an interim measure to protect public safety while a long-term modernization project can be developed by Texas State University. Thus, rather than a specific design storm, the hydraulic design of the project is based on the pre-disaster condition of the dam and the immediate possibility of further damage to the dam from overtopping. Overtopping of Spring Lake Dam represents a complex hydraulic situation that cannot be easily characterized by 1D or 2D models. FNI developed a computational fluid dynamics (CFD) model to assess the qualitative hydraulic performance of the proposed repairs and identify areas of potentially high scour potential due to high velocities and shear stresses.

The model geometry was developed using a 2017 survey of the project site and geometry prepared by FNI of the proposed repairs. The domain of the model includes a portion of Spring Lake, Spring Lake Dam, the confluence of the two spillway channels, and the San Marcos River to the Aquarena Springs Drive bridge. The model was run using a grid cell spacing of 4 feet for the full domain, 0.75 feet for the embankment, and 0.5 feet for the two spillways. The software solves the Reynolds-Averaged Navier-Stokes equations, and turbulence modeling was completed using the Renormalization-Group algorithm. Boundary conditions included an upstream water surface elevation in Spring Lake and a defined tailwater elevation in the San Marcos River at the downstream end of the model based on the stream gage rating curve at this location. Simulations were run until the flow parameters reached a quasi-steady state condition.

2.2 CFD MODEL RESULTS

2.2.1 1 Foot Overtopping

The CFD model was run with an upstream water surface elevation of 576.4 feet to simulate approximately 1 foot of embankment overtopping at Spring Lake Dam. The model estimated the highest velocities (>20 feet per second) at the two spillways. Flow velocities over the top of the dam were generally less than 10 feet per second. No major flow concentrations were noted in the area downstream of the embankment.
under proposed conditions. Figure 2.1 shows the CFD model results colored by flow velocity for one foot of overtopping.

![Figure 2.1: CFD Model Results (1-Foot Overtopping)](image)

### 2.2.2 3 Feet Overtopping

The CFD model was run with an upstream water surface elevation of 578.4 feet to simulate approximately 3 feet of embankment overtopping at Spring Lake Dam. The model estimated the highest velocities at the two spillways, but significant flow velocity (>15 feet per second) was estimated across the entire embankment. The tailwater in this scenario is high enough to force a hydraulic jump along the entire toe of the embankment. This additional turbulence of the hydraulic jump and concentration of flows at the bend in the embankment would be expected to create an increased scour potential along the downstream toe of the dam. Figure 2.2 shows the CFD model results colored by flow velocity for three feet of overtopping.
2.3 ROCK RIPRAP DESIGN

A 24” nominal rock riprap was selected for repair of the scour damage. This is a commonly-available size of rock riprap from nearby quarries and is consistent with the rock used in the 2001 scour repair project on the west side of the embankment toe which withstood the 2015 flooding with minimal damage. The void space in the rock riprap will be filled with concrete grout to interlock the rock mass and provide additional protection against potential future scour damage.

3.0 GEOTECHNICAL DESIGN

3.1 SEEPAGE ANALYSES

FNI performed a two-dimensional seepage analysis for the existing embankment using estimated hydraulic parameters for the various materials. Assuming the upstream slope has a continuous clay liner, two feet in thickness, the seepage rate is approximately 0.005 gpm per foot of embankment. Introducing a 12-inch defect in the clay liner results in an increase in the seepage rate to over 400 gpm for the single defect. This analysis highlights the importance of the upstream liner to the overall function of the embankment and the dam’s vulnerability to damage of the liner (e.g. scour during flooding, tree roots, animals, etc.).
It is unlikely that a separation/filter medium was placed between the clay liner and the rockfill core. If the filter is missing, there is potential for the clay liner to erode through the large rockfill void space. This type of erosion would result in the formation of a “pipe”, connecting the reservoir directly to the rockfill core. Uncontrolled seepage presents a significant dam safety concern. If left unaddressed, flowrates and seepage velocities may increase, allowing for larger and larger particles to erode, and the potential for an uncontrolled release of the reservoir.

The proposed design includes measures to repair damaged portions of the existing clay liner with bentonite-aggregate composite to reduce the volume and velocity of seepage and reduce the dam’s vulnerability to this failure mode. This material is intended to serve as an interim repair to the liner while a comprehensive solution to the dam’s deficiencies can be developed. Locations of the liner repairs were selected based on an underwater investigation and dye tracing study performed by staff of the Meadows Center for Water and the Environment [6]. Figure 3.1 shows the locations and extents of major seepage features as of May 2018. Areas of significant seepage inflow are marked as green dots and purple lines along the upstream face of the embankment. Areas of seepage exiting the toe are marked in red. The orange extents delineate the areas with standing water from seepage through the embankment.
Figure 3.1: Seepage Locations and Extents [6]
3.2 SLOPE STABILITY ANALYSIS

FNI performed a stability analysis of the embankment to assess the existing and proposed conditions of the dam. The embankment geometry was developed from a 2017 topographic survey [8]. Subsurface conditions were assumed based on recent geotechnical investigation data [5] and historical information related to the dam’s construction. Limited data are available for the materials of the embankment itself since past investigations have only collected samples adjacent to the dam. Shear strength parameters were estimated for the dam and foundation materials based on the following assumptions:

- The upstream clay liner consists of materials similar to the clay foundation material;
- The rockfill core and downstream riprap consist of similar material, and no reinforcement accounted for by existing cribbing within the core;
- Rockfill consisting of angular and subangular quarried limestone;
- Fat clay foundation material with a liquid limit of 71 and plasticity index of 50;
- Seepage (groundwater) conditions based on seepage analysis results.

The estimated strength parameters are summarized in Table 3.1. Based on these assumptions, the embankment appears to meet TCEQ dam safety slope stability requirements, with estimated factors of safety calculated for the upstream and downstream slopes greater than 1.5.

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit Weight (pcf)</th>
<th>Shear Strength</th>
<th>Friction Angle</th>
<th>Cohesion (psf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockfill/Riprap</td>
<td>125</td>
<td></td>
<td>35°</td>
<td>0</td>
</tr>
<tr>
<td>Clay Embankment/Foundation</td>
<td>125</td>
<td></td>
<td>19°</td>
<td>125</td>
</tr>
<tr>
<td>Bedrock</td>
<td>130</td>
<td></td>
<td>27°</td>
<td>100</td>
</tr>
</tbody>
</table>
4.0 STRUCTURAL ANALYSIS AND DESIGN

4.1 DESIGN PARAMETERS

The proposed east spillway repairs include a reinforced concrete slab. Material properties used in the design were developed from geotechnical data from previous studies and standard engineering practice for similar applications. The following table summarizes the material properties used in the spillway stability and structural design.

Table 4.1: Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Unit Weight</td>
<td>150 pcf</td>
</tr>
<tr>
<td></td>
<td>28-day Compressive Strength</td>
<td>4,000 psi</td>
</tr>
<tr>
<td>Steel</td>
<td>Unit Weight</td>
<td>490 pcf</td>
</tr>
<tr>
<td></td>
<td>Bar Yield Strength</td>
<td>60,000 psi</td>
</tr>
<tr>
<td>Water</td>
<td>Unit Weight</td>
<td>62.4 pcf</td>
</tr>
</tbody>
</table>
4.2 FLOATATION ANALYSIS

As discussed previously, the stabilization designs are not based on specific loading conditions or a design storm event but rather returning the dam to its pre-2015 condition. No historic data was available on the design of the existing spillway, therefore approximate flow depths were selected based on the hydraulic analysis to determine the flotation stability. The flotation analysis was performed under the guidance of USACE ETL 1110-2-307, *Flotation Stability Criteria for Concrete Hydraulic Structures*. For flotation stability, the recommended factors of safety are 1.3, 1.2, and 1.1 for usual, unusual, and extreme conditions, respectively. The spillway was evaluated for flow depths of 1 ft (usual condition), 5 ft (unusual condition), and 8 ft (extreme condition). The calculated factors of safety exceed the recommended factors of safety for all conditions.

4.3 REINFORCED CONCRETE DESIGN

The concrete slab was designed as a one-way slab to resist the hydraulic weight of the flow depths over an unsupported span of 12 feet. The reinforcement was designed and detailed in accordance with ACI 350, *Code Requirements for Environmental Engineering Concrete Structures* [1].

5.0 ENVIRONMENTAL EVALUATION AND PERMITTING

5.1.1 Endangered Species

As a federally-funded project, Section 7 of the Endangered Species Act requires FEMA to coordinate with the U.S. Fish and Wildlife Service (USFWS) to ensure that the actions will not jeopardize the existence of any species. There are four federally-listed species of concern that could potentially occur within the project area: Texas wild-rice, Fountain Darter, San Marcos salamander, and Comal Springs Riffle Beetle. FNI submitted a Biological Assessment for the project to FEMA on April 20, 2018. FNI was notified via email from Patrick Connor that the Biological Assessment was submitted to USFWS on May 31, 2018. USFWS finalized their Biological Opinion (BO) on September 24, 2018 [7]. The BO includes reasonable and prudent measures to minimize effects of incidental take of federally-listed species summarized below:

1. Avoid disturbance of federally-listed species to the extent possible. Where avoidance is not practical, minimize disturbance in space and time.

2. Monitor the project and ensure appropriate and relevant information is provided in a timely manner to FEMA, USACE, and USFWS.

3. Ensure coverage of submergent aquatic plants is not permanently reduced by dam repair activities.

The BO also includes non-discretionary terms and conditions for the project summarized below:
1. Ensure that conservation measures and environmentally protective actions described in the Biological Assessment are followed.

2. Manage the use of heavy equipment on the dam carefully to avoid leakage of fuels, hydraulic fluids, coolants, other fluids, or other foreign matter falling into the river.

3. Biological monitors working to clear federally-listed species from the construction area will carefully move these species to nearby suitable habitat outside the work areas.

4. Captured fountain darters and San Marcos Salamanders will be released in a manner that avoids predation by larger fishes by releasing individuals near plant cover on the river bed. Biological monitors will have proper equipment and authorizations/permits to handle listed species.

5. Monitor turbidity in the San Marcos River above the University Drive bridge. If turbidity precludes light reaching the river bed, notify USFWS.

6. Translocated any stands of Texas wild-rice plants occurring in an area to be disturbed by construction with written approval by USFWS and Texas Parks and Wildlife Department.

**5.1.2 Jurisdictional Waters of the United States**

Jurisdictional waters of the U.S. (WOTUS) are located in the vicinity of Spring Lake Dam, including Spring Lake and the downstream spillway channels. The emergency stabilization project includes placing fill materials below the ordinary high-water mark (OHWM). As such, a permit will be required from the U.S. Army Corps of Engineers (USACE) under Section 404 of the Clean Water Act. FNI is coordinating with USACE on the project. Comments from USACE may require modifications to the contract documents.

**5.1.3 Historic/Archeology Considerations**

As a federally-funded project, Section 106 of the National Historic Preservation Act would apply to any excavation activities. Portions of the dam are eligible for listing on the National Register of Historic Places as a State Antiquities Landmark. FEMA engaged in formal coordination with the Texas Historical Commission (THC) [3] to determine potential impacts to cultural resources from construction activities and has provided project requirements summarized below:

- Exposed wooden posts along the top of the dam shall not be covered.
- Timber mats shall be used to protect the area at the toe of the dam from vehicular traffic.
- Removal of brush and small trees is not allowed along the river banks.
- Heavy equipment is not allowed on the dam.
6.0 OPERATION AND MAINTENANCE REQUIREMENTS

In Texas, the owner of a dam can be held liable for damage resulting from failure to maintain, repair, or operate the dam safely and properly. TCEQ requires that dam owners develop and implement an operation and maintenance program. Such a program would include preventative maintenance, regular inspections, and performance monitoring to maintain the safety of the structure. Prior to completion of the emergency stabilization project, FNI recommends that Texas State University finalize a formal operation and maintenance program for Spring Lake Dam.
7.0 REFERENCES


