

SUMMARY OF FINDINGS

PHASE I 2017 DAM SAFETY INSPECTION LAKE LURE DAM & APPURTENANCES LAKE LURE, NORTH CAROLINA North Carolina Identification No. RUTHE-003

Prepared For:

**Lake Lure Town Council
Town Council Meeting
October 10, 2017**

Prepared By:

**B. Dan Marks, Ph.D., P.E., Principal
NC Registration No. 09631
Marks Enterprises of NC, PLLC
Firm NC Registration No. P-0199**

SUMMARY OF PHASE I INSPECTION FINDINGS
2017 DAM SAFETY INSPECTION
LAKE LURE DAM & APPURTENANCES
LAKE LURE, NORTH CAROLINA

INTRODUCTION

The purpose of the Phase I portion of the 2017 Dam Safety Inspection of Lake Lure Dam and its appurtenances was to determine the current condition of the dam and associated facilities such as spillways, gates, overlying roadway, powerhouse, penstocks, etc. and the level of operation and maintenance activities relative to the overall stability, integrity, and safety of the dam by conducting extensive visual inspections, monitoring excessive leakage and seepage from the dam, and reviewing all operation and maintenance records, reports, construction drawings, and communications with State Dam Safety Officials. The lack of the latter information and documentation of routine operation and maintenance activities was disturbing relative to existing dam safety issues. Beyond adequate operation and maintenance of the hydroelectric power generation facilities there is little evidence that any routine operations, maintenance, and inspections have ever been done. This philosophy concerning improper upkeep, caretaking, and concentrated attention to the most important amenity associated with the entire town did not occur overnight but was a gradual drifting away from responsible upkeep of a major portion of the infrastructure of the town and surrounding community and the development of a complacent philosophy through the years based on the old saying “if it isn’t broke yet – don’t try to fix it”.

Prior to delving into the existing major issues and resulting major dam safety concerns relative to the performance and condition of Lake Lure Dam and its appurtenances, a brief discussion of orientation at a dam or river must be provided so that the reader is familiar with references to directions. In all countries except Canada and France the standard method of orientation at a dam or river is to position oneself so that you are facing downstream in the direction of the flow of water. On a dam, the reservoir or lake would be to ones back. In this position, the left abutment of a dam or the left bank of a river will be to ones left side. Conversely, the right abutment of a dam or the right bank of a river will be on ones right side. If one is travelling from the northern side of the dam to the southern side of the dam at Lake Lure Dam, one would be travelling from the left abutment to the right abutment. The bays (areas between the large reinforced concrete buttresses) at Lake Lure Dam have been numbered one (1) through thirteen (13), {Left Abutment to Right Abutment} and are marked with metal signs on the downstream side of the dam.

MAJOR DAM SAFETY ISSUES

Visual dam inspections, electronic surveying of critical points on the dam and its appurtenances, syntheses of inspection reports and Letters of Notification of Inspection by State Dam Safety representatives, monitoring of excessive leakage and seepage, and extensive experience with investigation and remediation design of existing dam have led to the determination that there are several major dam safety issues that are the cause of a significant number of dam safety concerns relative to dam safety at Lake Lure Dam and associated facilities. Major dam safety issues are presented below in no intended order of prioritization.

- Loss of both tensile and compressive strength of the reinforced concrete comprising the multiple-arch, slab-and-buttress type dam;
- Excessive leakage through construction joints that appear to also be “cold joints” between consecutive lifts of concrete placements;
- Solution and transport of cementitious compounds from the reinforced concrete through the numerous leaking construction joints in the reinforced concrete arches;
- Evidence of overstressing of reinforced concrete by deep spalling of exterior that exposes steel reinforcement thus allowing deep rusting and deterioration of flexural steel;
- Evidence of excessive seepage beneath the foundations of the buttresses that is creating excess hydrostatic pressure on the foundations (uplift pressure) that counteracts the weight of the structure and the resistance to potential overturning and sliding dam failures;
- Preliminary stability analyses at Bays No. 9 & 10 indicate less than acceptable factors of safety against both sliding and overturning under normal loading conditions (normal lake elevation conditions);
- Excessive leakage and sediment loss through the first construction joint above the top of foundation elevation in the Penstock Room of the Powerhouse that is the unfinished room immediately behind the Turbine Room one floor level below the Generation Room or Main Floor of the Powerhouse;
- Excessive loss of thickness of the riveted steel plate penstocks near junctions with smaller diameter penstock sections connecting the primary penstock to the turbine penstocks. The excessive loss of steel on the inside of the penstocks accounts for the reduction of thickness of the plate steel from one-half inch to less than one-eighth inch at some locations. Rupture of the penstock at one or more of these minimum thickness areas must be considered to be a highly-probable dam failure mode; and
- Finally, the extremely poor condition of the roadway bridge that crosses the dam. Simple removal of the bridge is not possible since its weight is a major component of the resisting force against both overturning and sliding dam failure.

CONCERNING DAM SAFETY CONDITIONS

There are so many conditions associated with Lake Lure Dam and its appurtenances that raise concern relative to the stability and integrity of the dam that it is almost impossible to present these concerns in any order of prioritization. As such, the author has elected to present major dam safety concerns in the order of location without any reference to prioritization. Completion of the Phase II Inspection (Investigation) that will include laboratory testing of recovered concrete core samples, test borings and piezometer installations, and more detailed measurements of leakage and seepage quantities will provide data that will be used not only to prioritize the dam safety conditions but also provide technical data upon which dam remediation design will be based. These data will be used to reinforce or discredit preliminary evaluations of dam safety issues presented in the previous section of this summary. Conditions observed in the Phase I Inspection that have raised dam safety concerns are presented below.

- The left abutment wingwall exhibits the presence of a significant amount of water that is presently being drained through weep holes in the retaining wall. The water level has risen approximately five (5) feet behind the wall since the author first began to observe the dam for preparation of the first proposal for this investigation in 2014. Preliminary stability analyses indicate that the wingwall will become unstable if the retained water level rises another three (3) to five (5) feet. Failure of the wingwall will undoubtedly result in a slope failure at the left abutment that will partially block the first bay of the Ogee Spillway structure. Obstruction of this bay of the spillway will reduce the discharge capacity by approximately one-third which could potentially catastrophic in the case of a need to release water during a significant storm event.
- The Ogee Spillway structure located in the first three bays of the dam beginning at the left abutment is the most stable sections of the dam. The Ogee Spillway is constructed as a gravity dam section consisting of mass concrete bearing on a bedrock outcrop. There has been some removal of bedrock at the outlet of each of the Ogee Spillway sections; however, this is not considered to be a dam safety concern at this time. Similarly, there is a significant amount of lateral spillway discharge flowing along the toe of the dam that shall be remedied; but, it is not considered to be a dam safety concern at this time.
- Both the fourth (4th) and fifth (5th) bays contain significant construction joint leaks that will continue to deteriorate if not repaired. As such, these bays will likely be the subject of dam remediation efforts in two (2) to three (3) years. However, this estimation may have to be revised since the major sewer collector and discharge line penetrates the dam in Bay No. 5 which could be affected by efforts to upgrade the entire sewer system at Lake Lure.

- Bay No. 6 is one of the better arch slab bays with some minor leaks at construction joints but none that appear to be of major concern relative to dam safety at this time. The lateral flow of spillway discharge previously mentioned flows into Bay No. 6 where it forms an eddy and flows back out of the bay and into the tailrace of the Powerhouse that is located in Bay No. 7. Issues associated with the Powerhouse have been discussed in detail previously and will not be repeated here. Bay No. 8 is the electrical transmission bay where generated electricity is transmitted to the substation at the right abutment of the dam. There appear to be no dam safety concerns in Bay No. 8; however, it is located adjacent to Bay No. 9 which is one of the two bays that present the authors major concern relative to potential hydrostatic uplift acting on the foundations of the two buttresses on each side of Bay No.10.
- The author has major concerns about hydrostatic uplift pressures, potential scour during overtopping of the dam in 1996 and 2004, and excessive leakage through a construction joint below ground surface in Bay No.10. A weir was installed in the outlet stream of leakage and/or seepage flow originating from a “boil” (upward flowing water from seepage beneath a dam) located in approximately the center of Bay No. 10. Following the overtopping event of 1996 a concrete sump and slab was constructed in Bay No. 9 reportedly to catch leakage from construction joints; however, monitoring of the outflow from this concrete sump indicates that the slab may have been used to cap a “boil” in addition to catching surface water flowing from the leaking construction joints. At two (2) borings and one (1) piezometer will be located in Bays No. 9 & 10, and perhaps three (3) borings with two (2) piezometers and an additional V-notch weir to determine more precisely what is happening at this location.
- Except for some moderate to severe spalling of concrete and the deteriorating roadway bridge superstructure in Bays No. 11, 12, and 13 there appears to be little evidence of potential concern relative to dam safety. However, the right abutment end of the dam has the lowest crest elevation defined by the top elevations of the multiple arches. As such, the right abutment side of the dam is the first to overtop. The author has made no decision about this unique situation relative to such a significant variation in the crest of the dam defined by the variation in elevations of the tops of the arch slabs. This should not be a major dam safety concern unless the factor of safety for the unusual loading condition is found to be the controlling remediation design condition.

The author of this summary report will make a formal presentation near the conclusion of the Phase II field exploration and laboratory testing programs. A more definitive prioritization of dam remediation activities will be presented at that time with an indication of the remediation design and construction schedules.