BIG BAY DAM

EVALUATION OF FAILURE

BIG BAY LAKE
LAMAR COUNTY, MISSISSIPPI

PREPARED FOR:

LAND PARTNERS LIMITED PARTNERSHIP
HATTIESBURG, MISSISSIPPI

APRIL 27, 2004

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INTRODUCTION AND PURPOSE

The Big Bay Lake Dam failed on Friday, March 12, 2004, at approximately 12:20 p.m., under clear, sunny sky weather conditions. The uncontrolled release of approximately 7.2 billion gallons of stored water occurred over the following 2 ½ hours, completely draining the 945 acre lake. While the ensuing downstream flood caused extensive damage and loss to property, miraculously no injuries nor deaths were sustained by the effected population.

Immediately following the failure, Joseph F. Tatum, Jr., president of Land Partners, L.P., instructed this firm, Timothy R. Burge, P.A., Inc. to assist with the restoration of ingress/egress, and service utilities to the western side of the lake bed, and then conduct a study into the failure of the dam. It is pointed out here that this firm has maintained a professional association with the dam and its owner since shortly after completion of construction of the dam. This association has been in the capacity as engineering consultant for matters pertaining to the operation and maintenance of the dam as directed, and for the residential development of property adjoining the lake. Further, Timothy R. Burge, P.E., principal of Timothy R. Burge, P.A., Inc, was previously employed with the engineer of record for the dam, at the time of its permitting by the Mississippi Department of Environmental Quality, and was active in the original engineering and construction of the dam. This point being made solely to establish this firms experience and familiarity with the design, construction, and operation of the dam and structures since it's inception.

The purpose of this report is to present to the results of this firm's investigation and evaluation of the failure of the Big Bay Lake Dam directed toward determining the most probable cause of failure.

SCOPE

This report is primarily focused on determination of the probable cause(s) of failure of the dam, and related technical details. It is not intended for the evaluation of methods, procedures, actions, or responsibilities of any parties with regard to the dam, nor the determination of any liabilities therefor, as such, no part of this report should be interpreted as so doing.

The loss of that portion of the structure (1/4 of the dam in this case) that failed does lend some handicap to the evaluation process, however, this consultants familiarity with the dam, and actual presence prior to and during the failure will contribute to the conclusions developed in this study. Also used in the scope of this evaluation are field survey measurements of the failure section, field investigation of the remaining dam structure, and review of original design and construction records.

DESCRIPTION OF THE DAM

Big Bay Lake is located in southwest Lamar County, Mississippi. The dam was situated across the Bay Creek basin, and was designed to impound runoff from approximately 6000 acres of watershed. At normal pool elevation, the dam created a lake surface area of approximately 945 acres. The longitudinal axis of the dam is concave downstream and is oriented in the east-west direction. The dam proper has an embankment length of 1890 feet from the west abutment to the east abutment, but appeared longer due to extension of the roadway crest by excavation into the east and west abutments. A 200 foot wide emergency spillway is excavated into natural ground at the eastern approach.

The dam has a crest width of 40 feet, and a maximum base width of 363 feet. Maximum height of the dam from the lowest natural ground elevation in the creek basin to the high crown point at the crest is 52 feet. Front and back slopes of the dam are three horizontal to one vertical (3:1). The front slope contains a 12 foot wide rip-rap armored wave berm at the normal pool elevation, and the back slope contains two 10 foot wide safety berms at the approximate one/third height points. Relative to mean sea level, the dam has a crest elevation of 284.0 feet, and lake surface at normal pool is at elevation 278.0 feet. The crest of the emergency spillway is at elevation 280.5 feet.

Hydraulically, the dam was designed to meet High Hazard Dam criteria as stipulated by the permit requirements and applicable regulations promulgated by the Mississippi Department of Environmental Quality(MDEQ). The dam is currently authorized under MSDEQ Inventory Permit No. MS03237. The dam's spillway system consisted of a concrete riser and discharge box culvert for passing of principal runoff flows, and the 200 foot wide emergency spillway previously mentioned for passage of the excess portion of the probable maximum precipitation (pmp) not discharged through the principal spillway riser. The concrete riser had a 48 inch diameter slide gate discharge assembly for controlled lowering of the lake pool.

Design of the dam embankment structure consisted of four basic sections. 1) The undercutting of the in-situ soils beneath the footprint of the dam base to remove soft compressible organic soils and other unsuitable materials to expose the underlying firmer clayey sands. This undercut depth ranged from three to six feet and was reconstructed with on-site clayey sand borrow soils placed in controlled compacted lifts back up to near natural ground elevations. 2) Pre-design soil bores indicated that no completely impervious strata existed down to depths of 50 to 60 feet at the bore locations, only moderately impervious sands of medium density. To create an impervious barrier, and lengthen the potential flow path, a soil-bentonite cut-off wall, 12 to 16 feet in width extending down below natural ground line to approximate depths of 15 feet at the abutment slopes to approximate 25 to 30 foot depths across the creek basin. 3) An impermeable core wall created by extending the soil-bentonite cut-off wall up into the embankment section. The core wall was terminated at 1 foot above normal pool elevation. 4) Front and back embankment sections constructed of on-site clayey sands excavated from borrow sites, placed and compacted in controlled lifts.

Construction records indicate that the embankment sections and the core wall were placed in a series of 47 lifts, with compaction test records indicating in-place densities of 95% or greater, of standard proctor density, with 95% being specified for construction. Permeabilities for the bentonite-soil modified cut-off and core wall ranged from 2.5×10^{-5} cm/sec to 1.5×10^{-7} cm/sec, with 1×10^{-6} cm/sec be the specified target value.

Toe drains, berms and slope drains utilizing "French drain" type construction were used for relief of percolation water at the back slope.

Construction of the dam began in August of 1990 with completion of the dam embankment and principal spillway structures by November of 1991. Completion of incidental items, toe drains, berm and slope drains, restoration of borrow sites, and crest roadway surfacing continued through November of 1993. The lake achieved normal pool storage level in January of 1993.

Upon completion. the dam and structures had required the placement of approximately 750,000 cubic yards of on-site excavated soils for embankment; 93,000 cubic yards of muck excavation for foundation preparation; 350 tons of imported bentonite for core/cut-off wall construction; 662 cubic yards of structural concrete and 92 tons of reinforcing steel for the principal spillway structure; and other incidental items. At an approximate cost of 1.8 million dollars.

CHRONOLOGY AND OBSERVATIONS OF FAILURE

On Thursday, March 11, 2004, at approximately 3:00 p.m. to 3:30 p.m., I received a phone call from Joseph Tatum, Jr. (Chip), stating that his maintenance man , Jim Daughdril, Jr; (Jim), had observed some increased discharge from the relief drain pipe at the west side wing wall of the discharge box, and that it appeared to have a slightly muddy tint. My response to him was that with the heavy and extended rainfall ending just a week or two prior, that I didn't think it was unusual for some of the toe and relief drains to have increased discharge with the elevated condition of ground water surfaces, as I had observed this pattern in times past on random visits to the site. I asked him if Jim had checked or "felt" of it to determine if it contained any soil fines or particles. Chip said he had and that nothing could be felt. Chip instructed me to take a look at it as soon as possible and advise him of necessary action. I told him I probably could not get to the site that evening, but would be down there first thing next morning.

On Friday, March 12, 2004, I was en route to the dam site at approximately 8:30 a.m. and received a phone call from Chip, he said Jim had called and reported that the drain discharge appeared to have a little soil material in it, and more of a muddy tint. I told Chip I was about 30 minutes away from the site and would call him as soon as I looked at it and determined what we may be dealing with.

I arrived at the dam between 9:00 and 9:30 a.m. and met Jim at the discharge apron behind the dam. My first observation was that the dissipation pool did have some muddy discoloration along it's western edge in an area about 6 feet in width and about 10 to 15 feet in length. While there was noticeable increase in discharge from the relief drain pipe, it appeared that the discoloration in the pool was being created from inflow further west of the relief drain pipe. After inspecting the rip-rap stone plating on the pool slope and adjacent to the west side of the west wing-wall of the discharge box culvert, a small flow was observed thru the rip-rap, coming from above the level of the pool and the drain pipe. Upon inspecting the ground surface area just off (south of) the toe of the dam, and just west of the discharge box wing-wall, a single point source seepage was found. The discharge was exiting the ground surface with an approximate ½ inch head height and approximate ½ inch diameter flow. Due to the slight sloping of the ground surface in their direction. the discharge was flowing across the ground surface, down through the rip-rap. and primarily into the edge of the dissipation pool and partially into the relief drain pipe via its perforated section beneath the rip-rap and gravel filter.

Using a piece of fine screen Jim had. I positioned it so the discharge could pass through it for approximately 1 minute and checked it for material. There were a few (approximately 10) grains of fine sand retained on the screen. Although the discharge had some characteristics of a boil, there was no build-up of soil materials in a circumferential pattern around it, and no visible settlement of the immediate surface area. I attributed this to the minor amount of material detected in the discharge, and its low flow volume (I estimated it to be approximately ½ to 1 gallon per minute). Jim and I made a quick inspection of the back of the dam to check for any other similar discharges. None were observed.

We watched the seep for several more minutes while I explained to Jim what measures we would need to take to address it. I explained to him that I did not think it was indicative of seepage moving through the dam as that would likely have resulted in surface seepage from the berm slopes at a slightly higher elevation. Nor did it appear to be related to any malfunction of nor piping along the discharge box due to its location, and I was confident that the relief drain pipe discharge was largely from the infiltration of the surface runoff from the seep. I also told him that it could possibly be that the toe drain may not be handling the additional ground water it was receiving due to elevated ground water tables, and was forcing the discharge to the surface. But, I also felt that it could be indicative of a much deeper, sub-foundational seepage source. Either way, the coloration of the discharge dictates that we would need to monitor it closely for changes to determine how to handle it. I explained to him that if it did not increase in activity for the next one or two days, or hopefully, if it began to decrease, we would likely suspect some toe drain problem due to elevated ground water and treat it accordingly. Otherwise, we may be experiencing a "boil" occurrence and deal with it differently. I told him I wanted to make a closer inspection of the dam and discharge box and would then contact Chip to advise him. I told Jim I would be contacting contractors and material suppliers when I returned to the office to have them on standby, and, depending on our monitoring over the weekend, start corrective measures on Monday. I told him to monitor the boil regularly, until I could return after lunch, and let me know of any changes. Jim then left to resume his maintenance routine.

I made a walk-through inspection of the discharge box culvert and did not detect any apparent problems. Upon arriving at the site, I noted that the lake was approximately 6 to 8 inches above normal pool, and the box was discharging about a 4 inch flow depth at the downstream apron. There were no apparent movements or displacements at any of the joints, nor any unusual seepages occurring; the box and riser structure looked and were functioning very well. I checked the relief drain pipe at the east wing-wall and observed a very minor (approximately 1/4 inch flow depth) discharge of clear water from the 6 inch diameter pipe, which was not unusual.

I then again walked the east and west halves of the back slope of the dam to take a more thorough look at the berms and slope surfaces. The only other area of notice was at the interface of the west black-slope of the dam with the west abutment slope. There was some surface dampness in an area that had been monitored in the past. This location interfaces with the natural ground line of the west abutment back slope, in an area where blanket drains were installed as part of the borrow excavation site restoration. These drains intercept ground water percolation from spring heads exposed in the excavation areas during construction. After periods of extended rain, some of these areas would exhibit some surface dampness for short or seasonal periods of time. This area observation was considered not related to the boil location. The inspection of the back slope(s) did not yield any other problems. The drains in other locations were performing as expected.

I then walked the crest of the dam to look for any unusual indicators such as obvious settlement of areas on the crest or front slope; development of "eddy's or whirlpools" in the immediate lake surface; any unusual behavior at or in the vicinity of the riser structure; nothing was detected.

Except for the occurrence of the seep, the dam, spillway structures, and other appurtenances were performing flawlessly, giving no indication of impending or imminent problems.

I observed the seep again for about five minutes, and seeing no change, left the site at approximately 11:00 a.m. I called Chip to advise him of my assessment and get authorization to contact and mobilize contractors as needed. I discussed with him that I was considering bringing in a well point contractor contingent upon monitoring the next day or so. I pointed out to him that well pointing would drop the ground water in the area of the seep and facilitate reducing the pore pressure in the surrounding soils and would possibly reduce or stop the flow, if it was being "locally" charged. He authorized me to take whatever measures necessary and keep him advised.

At approximately 11:30 - 11:45 a.m., prior to my arriving back at the office, Jim called me to say that the flow appeared to have increased. I told him I still needed to make contact with contractors, and would return as soon as I had completed that. Deciding to try and make calls on the way there, I turned and headed back to the site.

At about 12:15 p.m., Jim called and said it looked more serious now. (Cell phone contact was poor at this point) When I asked him what it was doing he said water had "shot up out of the hole," and could I get there quick. I told him I was only seconds from the gate and asked if he had called the office or 911 to activate the plan. However, cell phone contact had been lost.

Arriving back at the site, I went back to just east of the discharge box apron area and observed that the seep appeared to be spouting approximately 2 to 3 feet in height, with a diameter of about 18 inches. Quite suddenly, the area around the boil appeared to liquify and/or settle downward and rapid erosion set in to the north (back slope of the dam) and to the south (down-stream direction). Erosion into the back slope of the dam progressed quickly. Not being sure of the magnitude of what might be about to happen, and thinking full breach was likely, I went up to the crest to make observations and locate Jim to see what emergency actions had been called in.

From the crest, the erosion or collapse of the backslope appeared to be occurring from the bottom upward and or from beneath. Once the erosion cut through the crest of the dam, breach of the rip-rap wave berm was rather smooth and steady, instead of rapid and irregular. Uncontrolled release of the lake pool began at approximately 12:25 p.m.

At 12:25 p.m. I received a call from Chip's office as a result of the emergency action plan implementation.

At approximately 12:30 p.m. I was able to reach Chip by cell phone and told him that the dam was in a state of uncontrollable breach. He advised me that the emergency action plan had been activated ten (10) minutes prior, and that he would see me at the lake site shortly. Following is the time-line of the draining of the remainder of the lake pool:

> 12:40 p.m. Breach width along crest of dam is about 75 feet in width. Riser structure intact, flood pool at back of dam at ± 244 elevation, normal pool down ±2 feet.
>
> 12:50 p.m. Breach widened to about 150 feet, riser intact, flood pool at lower berm (±252), normal pool down ±5 feet.
>
> 12:55 p.m. Riser structure collapses.
>
> 1:05 p.m. Breach width and depth widens, riser body lodged in dissipation pool.
>
> 1:10 p.m. Breach widens to ±200 feet, normal pool down 12 feet.
>
> 1:15 p.m. Flood pool peaking at 3 feet above lower berm (±253).
>
> 1:20 p.m. Normal pool down ±16 feet.

1:30 p.m. Flood pool subsiding, down 2 feet (±251), flow through breach beginning to stabilize.

1:35 p.m. Tailwater surface at about 5 feet below lake pool, lake pool down about 20 feet.

1:40 p.m. Flood pool down to 3 feet below lower berm, breach about 350 feet wide.

1:50 p.m. Lake pool and flood pool equalized at about 4 foot below lower berms (±248), lake pool down ±30 feet.

1:55 p.m. Flow through breach is stable.

2:10 p.m. Flow through breach beginning to slow, water surface at about 8 feet below lower berm (±244).

2:25 p.m. Flow continuing to slow, flood pool dropping rapidly, scour hole becoming visible.

2:40 p.m. Water surface at about 240 elevation, flow very stable.

3:05 p.m. Water surface at about 238 elevation.

3:40 p.m. Lake bed empty.

POST FAILURE SITE CONDITIONS

Field survey measurements show the final widths of the breach cut through the dam to be 396 feet at and along the crest centerline (elevation 284), and an average of 235 feet where the water surface of the resulting scour pool meets the east and west breach faces (elevation 236). The breach faces are vertical with the sloughed material at their bases having slopes of about 1 vertical to 1 horizontal. In both breach faces, in the back slopes, the ends of the toe drains and berm drains were exposed. Small diameter PVC water and sewer lines were visible in the front and back shoulder sections of the crest.

The scour hole created underneath the breach section began at about 30 feet downstream of the original upstream toe line of the embankment and extended south for 840 feet, about 515 feet south, or downstream, of the original downstream toe line. Averaging 240 feet in width , the scour pool surface encompasses 4.3 acres. The longitudinal axis of the scour pool is curvilinear, diverging south westerly along its length downstream of the dam. Average centerline depths of the pool along its axis are 30 feet for the portion beneath the dam footprint, and 15 feet for that portion downstream of the dam.

Volumetric calculations indicate that 101,500 cubic yards of soils were displaced beneath the surface of the scour pool, and 221,200 cubic yards of dam embankment were lost above the breach footprint. No evidence of the concrete spillway riser structure nor the discharge box culvert remain in the original locations. Approximately 1/4 mile downstream, two sections of the 8 foot square box culvert were found protruding from the sediment, both sections totaling about 80 feet of the 280 foot box structure. These sections were lying to the east of the original creek centerline. Substantially west of the creek centerline about 1/5 mile downstream of the dam, on an extended alignment with the curvilinear axis of the scour pool, fragments of the riser structure top slab were scattered.

CONSIDERATION OF FAILURE HYPOTHESES

In addition to the observed mode of failure, other possible mechanisms were considered as follows:

Failure of Riser or Discharge Box Structures. The inspection of the principal spillway system, less than 2 hours prior to the failure, found the structures to be very stable and functioning without incident. Their alignment, joints, and flow characteristics displayed no irregularities. There is no evidence of their failure or collapse as a cause of the failure.

Overtopping of the Dam. Under the sunny clear weather conditions occurring at the time, spillway riser structure was adequately passing all of the runoff discharge above normal pool. Overtopping was not a cause of the failure.

Sabotage. There was no evidence of sabotage.

Animal Burrowing. There was no evidence in the remaining portions of the dam; nor was any observed in the pre-failure inspection, that burrowing or tunneling by animals had occurred.

Earthquake/Seismic. Assuming the presence of liquefiable, cohesionless soils in the sub-foundational soil layers beneath the dam, and assuming a seismic event of the necessary magnitude, such an occurrence could have been a factor in the failure. Under seismic activity, the cyclic shear stresses induced in such soils causes a rapid consolidation and an increase in pore water pressure, resulting in an un-drained loading of the soil matrix. The pore water pressure increase causes the upward flow of water to the ground surface, becoming evident in the form of mud spouts or sand boils, some characteristics of which the observed seepage location displayed.

A review of records with the Office of Geology, MDEQ, indicates that there have been no recorded natural seismic events in the Lamar County area since construction of the dam. The only seismic type activity in the area within the last few years has been the residual effects of that artificially induced by geo-physical exploration operations. Due to the lack of evidence of this type of activity within the immediate time frame of the failure, seismic activity is not considered to have been a cause of the failure.

Seepage or Piping Through the Embankment Section. The occurrence of seepage directly through the embankment would likely have resulted in sloughing or sliding of the effected portions of the back slope. Continuous loss of a substantial enough volume of the back slope embankment would have shortened seepage paths, eventually leading to piping or continuous sliding. During the pre-failure inspection, evidence of such activity was particularly looked for. None was found on any portion of back slope in the vicinity of the break, nor elsewhere. Direct seepage through the embankment is not considered to have been a cause of failure.

CONCLUSIONS ON MOST PROBABLE CAUSE

Based on the pre-failure observations, and those of the initial development of failure, I believe that the primary cause of the failure was the development of rapid piping of soil and water from below the foundation structure of the dam, and not through the embankment or foundation sections. Construction testing records indicate that compaction of the embankment sections, and permeabilities and compaction of the soil-bentonite core/cut-off wall were maintained within their specified limits. I found no evidence to suspect that their performance integrity would have been compromised by poor or inconsistent construction measures.

The suddenness, or almost instantaneous development of the failure make it somewhat difficult to apply expected soil-water piping mechanisms to the observations. Assuming that seepage conditions favorable to piping developed in the sub-foundational stratum beneath the dam, this typically would have became evident by the appearance of seepage at the back toe surface area, eventually leading to piping and the transport of soils, becoming visible with boiling. Although the seepage had characteristics of a boil, the development of this process usually occurs slowly (days, weeks, months, etc., not minutes or short hours), before sufficient soils are lost to open flow paths to the point of allowing free flow of water, and increasing loss of soils.

While the movement of soil fines from some zone was obviously occurring, evident from the discoloration of the discharge, there simply was not enough time, nor evidence of sufficient loss of material volume to have created the observed drop of ground surface and rapid initiation or release of free flowing water and resulting embankment collapse. It would have been more probable that the rapid flow of water and internal erosion of soils would occur where seepage water is allowed to move in the presence of developing open paths or voids. A possibility for development of these voids would be the "cracking" of the foundational and sub-foundational soils under sufficient movement or settlement of the embankment structure. This magnitude of settlement has never been observed in any part of the dam, and the inherent flexibility of earthen embankment structures makes them relatively tolerant of differential settlements. This type mechanism is not considered to have contributed to the failure mode.

As mentioned earlier in the report, the observation of the initiation of the failure included the rapid liquefaction and/or rapid settlement of the ground around the seep location. From the observation distance, this area is estimated to have been approximately 20 feet to 30 feet radial from the seep point. It appeared to have extended to some distance down and under the back toe of the embankment structure. To what depth this settlement occurred could not be fully seen as the discharge box structure blocked a lower line of sight. Based on the initial observation of that part which was visible, the face of the sloughed walls had at least a 6 to 8 foot exposure. Exactly what surface mechanism initiated the rapid settlement or drop is undetermined. As mentioned under previous hypotheses, liquifaction under seismic activity would generate similar occurrence, but is unlikely in this case. Another mechanism would be the development of a sink-hole type void at an appropriate depth, such that weakened shear strengths of a saturated soil matrix above it would decrease under additional pore pressures from seepage to the point of collapse.

The ensuing apparent horizontal downstream flow and movement of soil and water, some seconds thereafter, lends itself to the probability that this initial collapse of the seep area and collapsing of the adjacent sub-foundational soil prism under the embankment back slope section, led to the critical shortening of the flow path of seepage from under the cut-off wall. This now uncontrolled flow could develop rapidly and aggressively in volume and velocity to initiate, or continue, the upward and horizontal erosion and removal of the foundation and embankment section, leading to its breach moments later.

In summary, it is my conclusion that the most probable cause of failure development was the combined mechanisms of the initial unexpected collapse of the ground structure around the seep point, leading to the critical shortening of the seepage path beneath the cut-off wall. The result of which was the erosion and collapse of the embankment structure from within. Further, I believe the mechanisms leading to that development did not occur as a result of failure of any part of the dam design implemented to control or prevent such development, but rather because these mechanisms were abnormal and /or outside the scope of design. As eluded to earlier, a review of construction records gave no evidence that poor or faulty construction practices were found to have occurred. Also, I am of the opinion that maintenance and operation practices were not a contributor to the failure. It should be the expected responsibility of maintenance personnel to recognize potential problems in their regular observations of the dam structure, and report such to the owner, who in turn should contact appropriate engineering personnel. These were the procedures followed in this case.

End of Report

Timothy R. Burge, P.E.