14 Aug 2008, 4:30pm - 6:00pm

Investigation and Repair of a Leaking Earthfill Dam

Erik J. Nelson
Geosyntec Consultants, Tampa, Florida

6th International Conference on
Case Histories in Geotechnical Engineering, Arlington, VA, August 11-16, 2008

Investigation and Repair of a Leaking Earthfill Dam

Erik J. Nelson, P.E.
Geosyntec Consultants
Tampa, Florida 33637

ABSTRACT

This paper presents a description of the investigation performed on two leaking earthfill dams and the remedial measures undertaken to repair the dams. The dams are located at a large nursery operation that collects and stores excess irrigation water and storm water in five large on-site reservoirs. The both dams were built in 2001 and 2002 to increase the nursery's storage capacity by 40 percent.

In June 2004 water was found leaking into the outlet pipe in one of the dams through the joints and around the outside of the outlet pipe at the toe of the dam. Geosyntec was contacted to perform an investigation to find the cause of the leak and to identify potential repair options. During the initial observation, evidence of significant piping was discovered that indicated the dam may be unserviceable in its present condition. The outlet pipe was, therefore, excavated and removed. During repairs to the first dam the second dam began leaking as well. Subsequently this dam was also excavated and repaired.

This paper will present the results of the investigations performed prior to and during excavation, and a discussion of the repair measures undertaken after the forensic investigation was completed.

INTRODUCTION

In 2000, the nursery undertook an expansion of the planting beds which resulted in an increased need for irrigation water. In the past, the nursery had relied on a combination of water collected in three existing retention ponds, water recovered from an adjacent creek and well water. This increase in irrigation water demand resulted in an increase in the use of well water as the supply capacity of the other two water sources remained relatively fixed. Due to changes in the water regulations throughout the southeast, the owner decided to expand their on-site water collection and storage capacity. A series of investigations were undertaken by a local geotechnical engineering firm to obtain the required geotechnical information for construction of two additional retention ponds on the property.

PRELIMINARY INVESTIGATIONS AND DESIGN

Geotechnical investigations were performed at the two potential retention pond areas, Recycle Ponds 2 and 5 (RCP2 and RCP5). These investigations indicated that the RCP2 area was underlain by relatively clayey sands and sandy clays, and that sufficient borrow material was available at the site to construct the dam. The investigation for the RCP5 area indicated that the surface soils at the site were clayey sands. The remainder of the site was underlain by a silty sand with relatively high permeability.

The geotechnical report found that sufficient clay material did not exist in the immediate area of RCP5, and therefore, clay would need to be imported from other areas of the nursery. The report further recommended that the pond area be lined with clay or treated with a proprietary permeability reducing additive to reduce seepage losses from the pond.

Both dams were ultimately designed assuming that the same basic materials would be used for both dams. The basic design consisted of a conventional clay core earthfill dam, with a six foot diameter outlet pipe placed at the low point of the dam. As designed, the water depth in RCP2 was 14 feet deep at the outlet pipe and 33 feet deep at the outlet pipe in RCP5. The outlet pipe for both dams consisted of a 6 foot diameter corrugated metal pipe (CMP) laid horizontally through the dam, connected to a 12 foot diameter vertical section on the pond side. The top elevation of the vertical pipe was set approximately 4 feet below the crest of each dam. Both 12 foot diameter sections were equiped with an 18-inch diameter gate valve located at the base to provide a way to drain the reservoir if needed. The base of each 12 foot diameter vertical section was set on a seven foot thick concrete foundation to resist the force of water falling down from the top of the overflow structure.

Construction specifications called for the base of the outlet pipe to be overbuilt by 2 feet, at which time the base would be shaped to accept the pipe bottom. The pipe would then be placed in the shaped trench and backfilled. The design plans called for a bolt-on seepage collar to be installed on the outlet pipe at the mid point of the clay core (Figure 1).

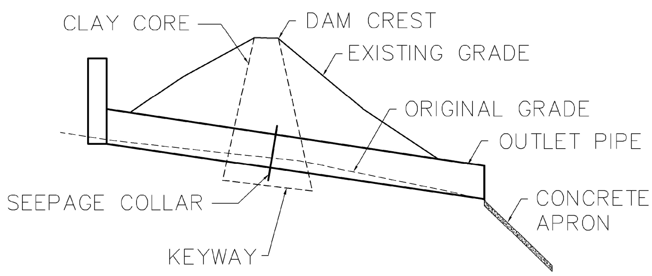

Figure 1 – Initial Design

Both dams were also designed with emergency spillways on the north abutment.

CONSTRUCTION

Recycle Pond 2

Dam construction began in late 2000 on RCP2. This dam was constructed across two small drainages. During construction, the contractor installed a 24 inch diameter pipe along the original stream bed to act as a stream diversion during construction of the lower portions of the dam. This diversion was supposed to be removed after the main outlet pipe was installed. However, during construction the contractor suggested to the owner that this pipe be left in place to act as an auxiliary outlet from the reservoir. The owner agreed and installed a gate valve on the pond side of the pipe.

During the initial filling of the reservoir, the owner detected a leak in the outlet pipe at the first joint in from the vertical section. The contractor excavated the first joint and placed a concrete seal around this joint.

RCP2 was then filled and placed into service in the spring of 2001.

Recycle Pond 5

Construction at RCP5 began in the summer of 2001. The small canyon in which this reservoir was to be constructed was heavily forested and overgrown wth brush. Vegetation, including trees and brush, was cleared, piled up in the reservoir area and burned.

Construction oversight was provided by a third party testing laboratory that reportedly provided periodic site visits. Construction was coducted by the same local contractor who constructed RCP2.

The leak in RCP2 prompted the contractor to place a concrete collar around the first joint to avoid the same leakage problems.

RCP5 was filled and placed into service in mid 2002.

DISCOVERY OF PROBLEMS

In 2003, seepage was noted around the end of the outlet pipe at RCP5. The design engineer, Northwest Florida Water Management District (NWFWMD), and the nursery operator decided to install a small french drain system on either side of the end of the outlet pipe to help aleviate the errosion and saturated soils caused by the seepage. This pipe was effective in reducing erosion due to the seepage in this area and reportedly had a stable flow of 5 to 10 gallons per minute.

In June 2004 the nursery operator noted a large amount of water exiting the outlet pipe during a routine inspection of the dam. Further investigation into the cause of the seepage found a large spray of water shooting into the outlet pipe at the second joint in from the overflow structure. The water was reportedly entering the pipe on the lower quadrant of the pipe and spraying completely across the pipe.

The operator imediately began draining the reservoir. The next morning the owner discovered that a large erosion feature had formed along the north edge of the outlet pipe at the toe.

Both the leak into the pipe and the seepage along the north side of the pipe subsided as the water level in the reservoir dropped. The owner reported that the large scale leaks stopped once the water level in the reservoir reached approximatley 8 feet above the top of the outlet pipe. Although, low volume seepage continued at all locations.

PRELIMINARY INVESTIGATION

Geosyntec was contacted the following week to observe the problem, meet with the NWFWMD and develop potential remedial measures. The initial site investigation was conducted five days after the discovery of the leak. During this investigation the condition of the dam and outlet pipe was observed and documented.

Seepage was found along most of the toe of the dam, but was concentrated around the end of the outlet pipe and extended approximately 100 feet in both directions along the toe.

An inspection of the interior of the outlet pipe found that three of the first four joints in the outlet pipe were were leaking. The only joint not showing signs of leakage was the first joint which was encased in concrete.

At the joint where the owner indicated the worst leak had been seen, the rubber gasket fron the pipe coupler had been blown into the pipe joint by the water pressure. Seepage was visible at all three joints and water would spray into the pipe at the next two pipe joints if the rubber gasket between the pipe sections was pushed on.

The owner reported that when the initial leak was discovered a large amount of soil was present in the pipe. Most of this soil was wasthed out of the pipe when the reservoir was drained.

Geosyntec also performed a tap test on the pipe. The tap test was conducted by hitting the interior of the pipe with a hard mallet and listening for the sound of voids behind the pipe. During this test, Geosyntec encountered what appeared to be a continous void along the length of the pipe. This void was mostly located in the lower half of the pipe and would migrate around the pipe from one side to the other.

GEOTECHNICAL INVESTIGATION

Field Investigation

Following the initial site visit Geosyntec scheduled a subsurface investigation to evaluate the condition of the soil within the dam and around the pipeline alignment. A series of nine borings were initially planned; five were located along the main axis of the dam and four more located along the north edge of the pipe alignment (Figure 2). One of the five borings located along the main axis of the dam was also placed along the edge of the pipe alignment. The borings located along the pipe alignment were surveyed-in so that the borings would fall within 12 to 18 inches from the edge of the pipe.

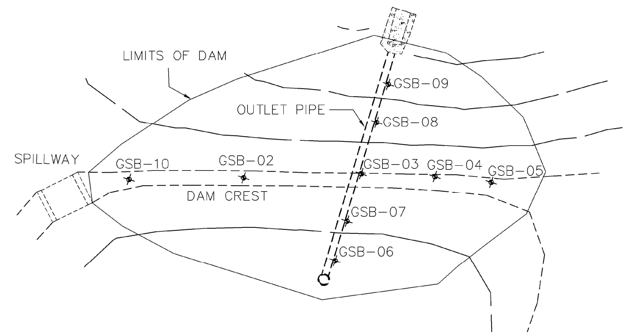

Figure 2 – Boring Locations

Three of the borings GSB-01, GSB-02, and GSB-04 were installed along the main axis of the dam. These borings encountered medium dense silty sands down to a depth consistent with the native soils underlying those points.

The forth boring, GDB-03, was located where the pipe alignment crossed the main axis of the dam. This boring encountered the same silty sands to a depth of approximatley 10 feet at which time a large void was encountered. This void extended for an additional 10 feet. Very soft soils were encountered after the void extending to approximately the invert elevation of the pipe. Below the pipe invert, dense silty sand was encountered.

All borings were backfilled with grout to avoid leaving a void in the dam structure. The first two borings were backfilled with 11 bags of grout. The third boring took over 40 bags of grout and was never filled up. Grout levels would reach within eight feet of ground surface, and settle to 11 feet below ground surface shortly thereafter. This observation confirmed the presence of a large continuous void in the dam.

Based on the field data collected from these four borings and the presence of at least one large void over the outlet pipe, it was decided to stop the geotechnical borings at that point since in-situ methods of repair were not likely to be reliable.

Laboratory Results

Samples of the soil collected from these borings indicated that the fines content of the soils placed in the core varied from 16.9 to 31 percent. Design specifications called for fines contents greater than 30 percent.

Density tests were also performed on shelby tubes pushed into the soil. In-situ soil compaction ratios were calculated to be between 81.8 and 98 percent of maximum density based on standard Proctor density. The design specifications called for compaction ratios greater than 98 percent of standard Proctor.

Record Search

The original contractor and construction quality assurance (CQA) consultant were contacted for information regarding the dams construction. The contractor claimed that the dam was constructed in accordance with the plans and specifications. The CQA consultant claimed to have taken tests and that all tests passed, however, they were unable to provide any reports or test records of the construction from either RCP2 or RCP5.

Geosyntec recommended to the owner that the outlet pipe be removed and that a forensic investigation be performed as the pipe was excavated. This data would allow the cause of the leaks to be better understood, leading to selection of an appropriate repair method.

PIPE EXCAVATION

Recycle Pond 5

Removal of the outlet pipe began in early 2005. As excavation proceeded, soil density and moisture content data was collected using a nuclear density gauge. Soil samples were collected to analyze for percent passing the #200 U.S. sieve.

Densities and moisture content data collected during the excavation indicated that soil compation ratios ranged from 74 to 95 percent compaction at moisture contents of between 1 and 14 percentage points over optimum moisture content. This data confirmed the data collected in Geosyntec's initial geotechnical investigation performed immediately following the discovery of the leak. The moisture contents collected indicated that the majority of the soil was at saturation and that the moisture content of the soil increased and density decreased as the excavation progressed closer to the outlet pipe. The excavation also showed that the dam was constructed of homogeneous soil throughout.

Vertical voids were encountered starting approximately 10 feet below the crest of the dam. These voids were relatively continuous and were oriented in a vertical pattern converging on the outlet pipe. Several of the voids encountered were filled with grout from Geosyntec's initial geotechnical investigation.

The outlet pipe was removed starting at the outlet end and working back toward the reservoir. Each section of the outlet pipe was 20 feet long. Each section was numbered so that it could be reinstalled in the same order it was removed. The pipe sections were connected by standard culvert band clamps that were 12 inches wide with a 12 inch wide buna ruber gasket.

As the pipe sections were removed it was noted that the soil placed under the haunches of the pipe was very soft and completely saturated. At the springline of the pipe a continuous piping void was encountered running laterally along the length of the pipe. The piping void showed several layers of erosion and redeposition. The soil redeposited in the void was primarilly clean sands indicating that the majority of the fines had washed away.

The seepage collar installed by the contractor was not in accordance with the project specifications. The contractor had replaced the bolt-on steel collar with a large mass of concrete. The contractor had excavated around the pipe after it was backfilled and poured concrete around the pipe. The mass of concrete that was removed during the excavation was approximatley ten feet by six feet at the top. The top of the concrete was approximatley 12 inches thick over the top of the pipe. The concrete mass narrowed as it went deeper around the pipe to the point where it pinched out under the pipe leaving a gap of approximately six inches (Figure 3).

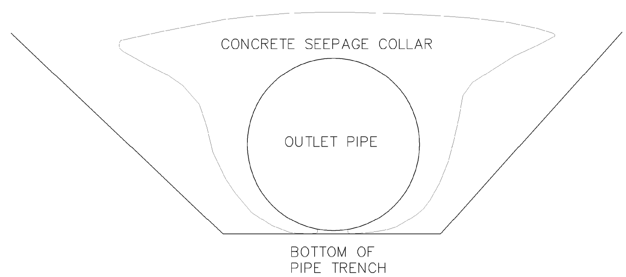

Figure 3 – Seepage Collar (as installed)

The piping void that was encountered along the springline of the pipe had reached the cutoff collar from the upstream side and then dove down under the pipe through the gap in the cutoff collar before running back up the pipe to the spring line.

The large voids that were encountered in the main body of the dam could be followed down to the sides of the pipe where they tied into the piping void along the spring line.

Recycle Pond 2

As the pipe removal for RCP5 was being performed, the nursery operator noted an increase in water flowing from the diversion pipe located under RCP2. The operator suspected that debris may have become lodged in the gate valve preventing it from closing. The valve was inspected and it was not found to be blocked indicating that the pipe was leaking internally.

In an attempt to avoid excavating this whole pipe, the operator opted to try grouting the pipe shut. The reservoir was therefore drained and the outlet end of the pipe was capped with a steel plate. Concrete was then pumped into the pipe. However, the amount of debris present in the pipe from the initial clearing operations prevented the concrete from completely filling the pipe. Therefore, the pipe needed to be excavated and removed.

During removal of this pipe it was noted that the pipe had basically been laid on the existing stream bed without any prior clearing or site preparation. In addition, because the pipe was laid directly in the stream bed it meandered with the original stream channel routing. Up to six feet of alluvial debris, including vegetation, organic clays and sands were found below the pipe.

In addition, it was noted that as the water level in the reservoir was drawn down, several small sinkholes appeared in the mud around the overflow sturcture. These small sink holes were ultimatley found to connect to leaks in the 12 foot diameter vertical pipe.

Soil densities in the dam for RCP2 were higher than the densities recorded in RCP5. In addition soil used in RCP2 had higher a clay content throughout the dam. The dam was still constructed without a clay core but the majority of the soil used in this dam was clayer than RCP5.

No leaks other than minor seepage were encountered in the joints of the six foot diameter outlet pipe.

CONCLUSIONS OF FORENSIC INVESTIGATION

Based on the data collected during the forensic investigation, Geosyntec identified several contributing causes to the failure. Anyone of these causes could have resulted in a similar failure however, the combination of these causes resulted in a nearly catastrophic failure of the dam structure.

Recycle Pond 5

The mechanism of failure in RCP5 was associated with the normal seepage of water into the soil that comprised the dam. As the soil became saturated, the poorly compacted soil under the haunches of the pipe began to settle and pull away from the mechanically compacted soil above creating a void at this location.

Water began to flow along the pipe alignment following the resulting void and piping corrugations until it exited the piping void as seepage on the downstream end of the pipe. As the seepage increased, direct water pressure on the pipe joints also increased and the flow of water around these joints also increased resulting in even higher pressure on the coupler gaskets. The couplers used in this application were not designed for external presures and therefore began to blow into the pipe joints providing yet another pathway for water to drain from the dam.

As the flow of water began to increase, pore water in the sandier soils in the core also began to drain into this void. As pore water from the dam core drained into the void it dragged soil particles with it down into the void. This progressive errosion of the internal soil resulted in the voids encountered in the interior of the dam (Figure 4).

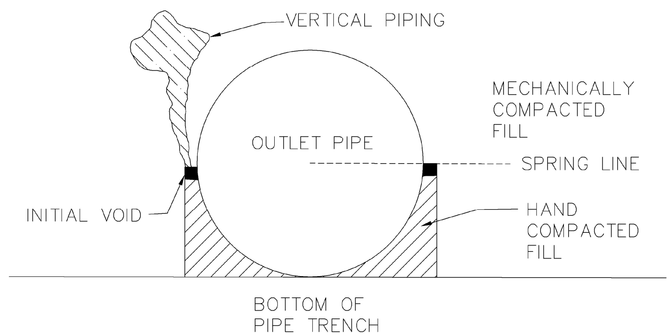

Figure 4 – Progression of Voids

The primary cause of the failure in RCP5 was found to be improper construction methods.

- The contractor did not place the outlet pipe as specified by the design engineer. The Contractor had laid the pipe on a flat base and tried to compact soil under the haunches of the pipe by hand tamping with pieces of wood.
- The contractor did not install a seepage collar as required by the project specifications. The seepage collar that was installed was insufficient and did not go completely around the pipe.
- The contractor did not place a clay core as required by the project specifications. This resulted in higher permeabilities in the dam and also placed more friable and erosion prone soils along the outlet pipe alignment.

Another contributing cause to the failure was improper material selection.

- Large diameter CMP is not a suitable outlet pipe for a dam of this height for a number of reasons: (i) It is not possible to get soil compacted into the corrugations on the under side of the pipe, and (ii) The pipe joints for CMP are not typically water tight.
- The standard culvert couplers used were not appropriate for the head experienced by the pipe. The culvert couplers used are intended for roadway construction where the joints are not subject to constant head. (Note: The Corps of Engineers has designed a higher head coupler design that should have been used. The higher head coupler is wider

and uses a wider gasket so that there is more material to stop leaks. Also the coupler is designed such that it can be tightened down more evenly around the pipe.)
- Lack of CQA inspections by the CQA consultant resulted in improper fill materials being placed, improper levels of compaction and poor soil and pipe placement practices.

Recycle Pond 2

The failure mechanism in RCP2 was settlement and corrosion of the 24-inch diameter diversion pipe. After construction of the dam, the weight of soil over the unprepared alluvial soils in the stream bed resulted in settlement of the pipe. As the pipe settled the pipe joints began to pull apart. The pipe was not intended as a permanent structure and therefore less care was taken in its initial placement. In addition, the number of bends and turns in the pipe resulted in questionable joints to begin with. The CMP that was installed was not coated and appeared to have been salvaged from an earlier application. A significant amount of corrosion damage was visible on the pipe when it was removed.

As the leaks began to grow, soil and rock washed into the pipe. This resulted in small voids around the pipe creating more seepage. It is likely that the higher clay content of the soil and the additional level of compactive effort provided around this pipe was responsible for preventing a complete washout of the pipe.

The primary cause of the failure on this dam is that there was limited if any CQA provided during construction. The design engineer was not consulted about leaving the diversion pipe in place and the pipe was not placed with the intent of being a permanent installation.

RE-DESIGN

Recycle Pond 5

Based on the data collected during the field investigation it was determined that the best course of action was to remove the outlet pipe and replace it. The nursery owner wanted to attempt to salvage the outlet pipe and reuse it if possible.

The NWFWMD required plans, specifications and a description of the repair operations prior to the start of work. The re-design, included:

- Complete removal of the outlet pipe and all soil above the pipe.
- The pipe excavation was to be sloped back at 1.5:1 from the bottom of the excavation.
- Excavation would proceed downward (a minimum of two feet below the pipe invert) and laterally until stable materials were encountered.
- A clay keyway was to be installed below the clay core extending five feet below the pipe invert elevation.
- A compacted clay pipe bed would be brought up to the pipe spring line (center of pipe) using clayey soil compacted to 90 percent of maximum density at 2 to 5 percentage points above optimum moisture content.
- The bottom shape of the outlet pipe was to be cut into the bedding soil and hand trimmed so that the soil would fit tight against the pipe. A special shaping tool was designed and constructed that could be dragged along the pipe alignment to assist in creating the proper shape for the pipe.
- A non reinforced geosynthetic clay liner (GCL) was then to be placed in the excavation and the pipe placed on top of the GCL.
- The GCL was to be wrapped over the top of the pipe and the pipe backfilled with clayey soil. The purpose of the GCL was to provide a means of filling the voids in the corrugations on the under side of the pipe. The plan was that as the bentonite saturated it would swell up into the corrugations and seal the bottom of the pipe.
- Clayey soil was to be placed for a minimum distance of two feet from the pipe in all directions.
- Three seepage collars were specified along the length of the pipe. The middle cut off collar was to be placed at the mid point of the clay core of the dam. The remaining two collars were to be placed 30 feet on either side of the middle collar.
- The seepage collars were to be constructed of reinforced concrete. The collars were to be excavated around and beneath the pipe and poured flush against the compacted soil.
- Each joint on the outlet pipe was to be encased in concrete to seal the joint.
- A clay core was to be installed in that section of the dam that had been excavated. Seepage would continue through the remaining portions of the dam and would be controled with toe drains.
- Soil with a higher permeability was to be placed on the downstream face of the dam to help with seepage control.
- Three subdrains were designed for the dam.
  - The first subdrain was to be placed below the clay material directly under the pipe.
  - Two additional subdrains were to be placed along the toe of the dam, extending 150 feet in both directions.

Recycle Pond 2

Because of the height of RCP2 (14 ft) the NWFWMD regarded the the activities on this dam as a minor repair. Therefore, complete plans and specifications were not necessary.

The NWFWMD did indicate that the pipe needed to be removed and the dam reconstructed according to the original design documents.

RECONSTRUCTION

Reconstruction of both dams took place in late 2005 and early 2006. As heavy equipment was already on-site for the RCP5 repair, the nursery operator opted to complete the repairs for RCP2 at the same time.

Recycle Pond 5

The outlet pipe alignment was overexcavated approximatley three feet below the original pipe invert. Suitable native soil was encountered at that depth. The bottom subdrain was installed and the clay pipe bedding brought back up. However, the nursery operator became uneasy with the idea of the CMP pipe after the previous two failures. The operator therefore, requested that an alternative method be developed to control the water level in the reservoir. Other recycle ponds on the property rely on siphon systems to provide overflow protection and to control water depth in the ponds so the operator suggested that this option be evaluated.

Geosyntec, developed a design for two 12-nch self activating siphons that could be located along the former pipeline alignment. The siphons were designed so that they would maintain a set pond elevation and would self start if the water level came within 3 feet of the dam crest. A siphon vent was intalled that would automatically shut off the siphons off at approximately 3.5 feet below the dam crest. An auxiliary connection was installed on the top of the siphon to provide a means for the operator to start the siphons in the event the system needed to be drawn down.

The siphon systme was designed to be capable of drawing down the reservoir in 24 hours. These siphons were not however, capable of passing a 100-yr, 24-hr storm event, even in combination with the existing spillway system. Approximately 14 siphons would have been required to provide this capacity. Therefore, the existing spillway was made deeper and wider than it had been previously. The spillway was also extended beyond the abutments of the dam and channeled into an existing wash located north of the dam.

A low permeability clayey sand was imported from other areas of the property. Laboratory testing indicated that the permeability of this soil exceeded 10^{-6} cm/sec and was therefore suitable. This material was used to create a clay core and to pack around the pipe as the excavated portion of the dam was brought back to the crest elevation. Higher permeabilty silty sands were placed on the downstream face of the dam to help depress the phreatic surface in downstream portions of the dam.

Although the outlet pipe was eliminated a french drain was still installed beneath the former outlet pipe alignment. The toe drains were also installed both north and south of the former outlet pipe alignment as originally planned.

Recycle Pond 2

The 24 inch diversion pipe was completely removed and the alluvial soils were removed down to suitable native material. The stream bed was backfilled with clay and a clay core was established in the repaired section of the dam.

Soil around the 12 foot diameter overflow structure and the first joint to the six foot diameter outlet pipe was excavated and encased in concrete to plug leaks into the overflow structure.

SUMMARY

Construction CQA is a vital part of any geotechnical project, but especially for critical structures such as dams. A catestrophic failure of RCP2 and RCP5 could have resulted in severe damage to downstream property and potentially could have posed a risk to people working or living downstream. The lack of adequate CQA during the initial construction of these two dams was responsible for the contractor being able to construct the dam in his own way. Short-cuts taken by the contractor should not have been allowed and adequate CQA would have identified these problems before they became issue.

Material selection is critical in dam construction. The selection of CMP pipes and standard culvert couplers was not an appropriate material selection for this application. It is very difficult to adequately seal the bottom of a corrugated pipe with out using special materials and construction techiques. The soil used in the initial construction of RCP5 was a contributing factor in this failure. If soil with a higher clay content had been used, the vertical voids may not have opened up as severely leaving the option of in-situ repairs such as pressure grouting as an option. However, once piping became evident throughout the dam structure presure grouting was no longer a viable option.

The placement of a proper seepage collar, a clay core, or proper bedding of the pipe could have averted, reduced or delayed the problems faced by the owner. However, the lack of all three in this case accelerated the failure process and lead to a near loss of the dam.