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**POTENTIAL FAILURE OF WEST GRAND LAKE DAM
DIAGNOSING AND AVERTING AN
IMMINENT FAILURE**

Abstract

The West Grand Lake Dam is located in eastern Maine on the west branch of the St. Croix River. The dam is approximately 487 feet in length, comprised of a 106 feet long concrete and rock-filled timber crib gate structure bordered on either side by an earth embankment. In 2003, the dam was subject to a Potential Failure Modes Analysis (PFMA) to conform to federal safety standards.

Out of several potential failure modes identified, the PFMA team considered the possibility for failure of the upstream cutoff wall leading to subsurface flow as the most severe candidate failure mode. If this process were occurring, material could be removed from below the dam with little to no indication visible to an observer.

On August 14, 2003, a potential failure situation developed at the West Grand Lake Dam. At that time, a significant flow was observed bypassing the timber gate structure and a silt plume was observed downstream of the dam, indicating erosion of foundation and ballast material from within the timber crib structure. Emergency measures were taken to prevent undermining and failure of the structure. At that time, a plan for permanent emergency repairs was conceived and implementation began immediately.

The permanent repairs included installation of a new cutoff wall, reinforcement of the gate piers, and placement of a new concrete apron. These modifications have effectively eliminated the possibility for this mechanism to develop in the future. This paper is a chronological description of the near failure of this dam, including the acknowledgement of the potential mechanism, diagnosis of the developing mechanism, and the permanent construction remedy devised to avert the failure.

Introduction

Prior to the potential failure and subsequent modifications, the West Grand Lake dam consisted of an earth embankment and a timber crib gate structure set behind a concrete trash rack structure and a fishway bordering the right abutment. Full pond in West Grand Lake is at elevation 301.43', and the available head of approximately 8.5 ft represents storage capacity of 160,900 acre-feet. The gate structure had five hand-operated wooden gates equipped with ratchet-type hoists. Integral with the timber apron upstream of the gates was a vertical timber cut-off wall. The existing project drawings indicated that the cut-off wall was installed to the naturally deposited alluvial material. The purpose of this cut-off wall was to prevent potentially damaging underflow.

Recent dam break analyses for the structure indicated that a dam failure during both sunny day and Probable Maximum Flood (PMF) conditions would potentially inundate both the State of Maine fish hatchery facility, located approximately 0.2 miles downstream of the dam, and a few residential structures along Grand Lake Stream. Analysis determined the incremental inundation of the fish hatchery starts at a discharge rate of approximately 3,000 cfs and increases to 5.8 ft at the PMF condition. Therefore, the Inflow Design Flood (IDF) for the West Grand Lake Dam was determined to be the PMF. The project is rated as a significant hazard dam.

Initial Response

On August 14, 2003 at 9:00 a.m. Kleinschmidt Associates, the independent consultant for the fifth Part 12 report and part of the PFMA core team, was notified of excessive flow (18 inch depth across the width of 9 ft) passing through the number five gate bay at the dam. This flow was occurring with the gate closed. Kleinschmidt was notified that some of the wood planking was missing downstream of the gate and water was boiling up through the apron and from the walls of the crib piers. It quickly became obvious that this was not a simple problem, rather much worse, a dam failure in progress. Emergency protocols were initiated.

By 1:30 p.m. Cianbro Corporation, working locally at the nearby mill, was mobilized at the site with plastic sheets, small sandbags, bulk grain bags, a mini excavator to fill the bags, and a truck crane to lower them into place. Instruction was given to attempt to locate the source of the underflow on the upstream side of the gates by use of a pick pole with a streamer (ribbon) attached to the end. Particular attention was to be directed to the location of the upstream vertical cut-off wall and the timber apron.

During the course of this inspection, several "hot spots" were detected along the cut-off location as well as along an existing concrete training wall between the gate structure and fishway. Sheet plastic was submerged with small sand bags over the suspect areas. Additionally, the contractor placed one cubic yard sized bulk grain bags on the areas of most concern.



Sandbags Filling Voids Upstream of Gate Apron

The temporary measures were effective at reducing the flow to a more tolerable level by 5:00 p.m., however nine inches depth of flow was still passing through the gate area. The conclusion was that the project was in an emergency condition. The Emergency Action Plan (EAP) notification flow chart was partially enacted, regional agencies were notified and informed that investigation was underway, and a security guard was put on 24-hour alert.

The emergency response team, consisting of a Domtar representative, Kleinschmidt Associates, and Cianbro Corporation, met early on the morning of August 15. A plan was conceived by 8:00 a.m. similar in concept to one Kleinschmidt Associates had used in 2002 to mitigate a similar type of failure of a timber structure. By noon that same day, the concept was faxed to regional agencies and a conference call took place early in the afternoon. To add to the excitement, there was a major power failure on the east coast going on at the same time adding to the communication challenge.

By the morning of August 16 the regional dam inspector, Mr. Harold Kamara, was on site to review the status of the situation and the temporary measures installed. The contractor was in the process of mobilizing a larger crane and steel sheetpile to be used as the cofferdam. By Monday, August 18, the contractor began driving steel sheetpile for the first phase of the planned cofferdam.

Design

The design concept was to drive a steel sheetpile cofferdam in two phases creating a dry work space to conduct demolition and replacement activities. The plan called for extending the sheetpile cofferdam into the embankment to create a seepage path long enough to prevent future piping. Both phases included closure seals at each end. Additionally, all work was to be

performed behind the cofferdam, allowing the placement of concrete in the dry. Phase I enclosed gate bays 3, 4, and 5. Phase II enclosed gate bays 1 and 2.

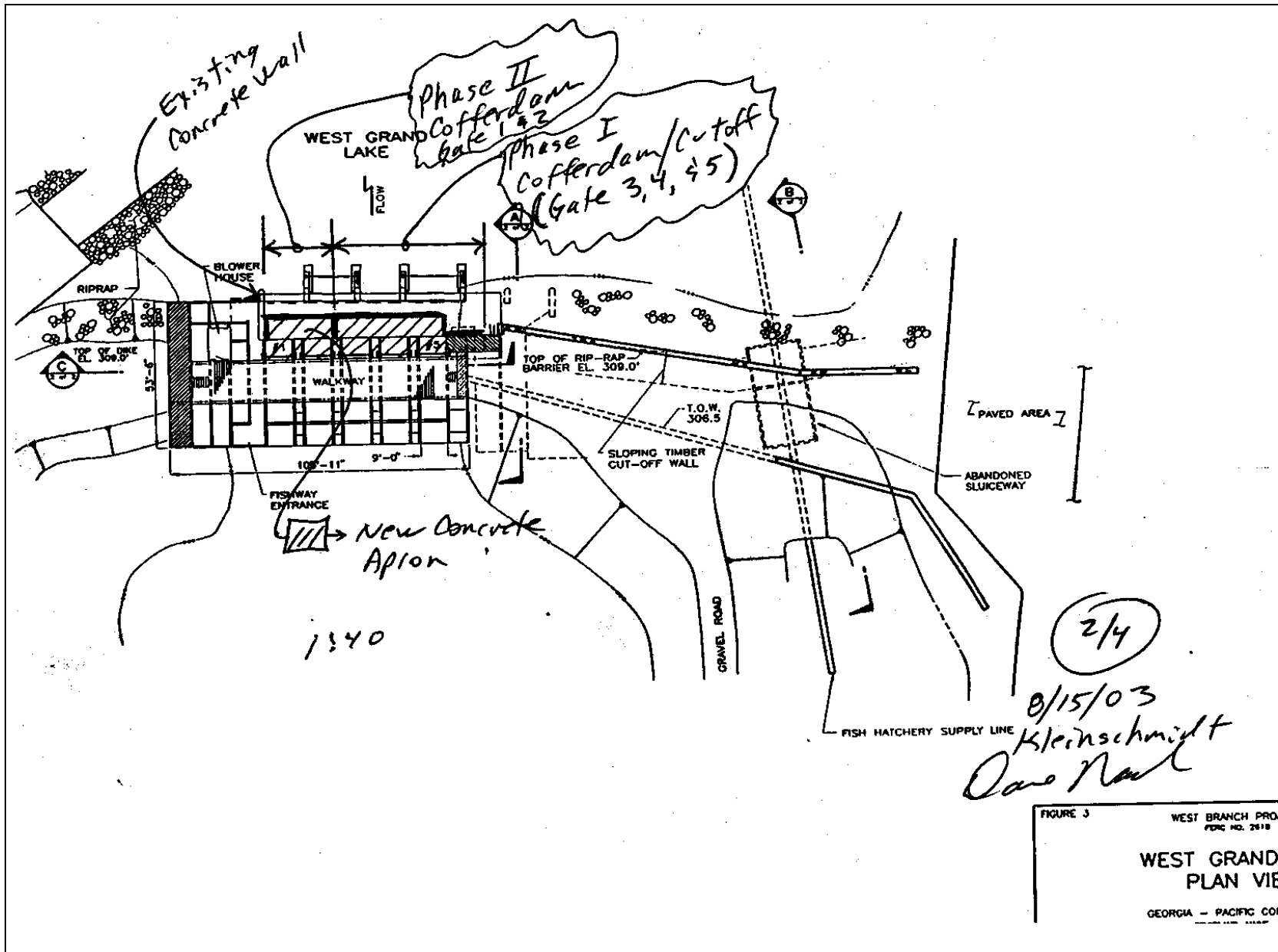


Installation of Phase I Cofferdam against Eastern Abutment

Once the first phase cofferdam was installed the timber portion of the gate structure was to be completely razed from the gates upstream to a level two feet below the gate sill apron. One of the thoughts behind the design concept was to design the new upstream gate structure to be fully stable and independent from the downstream timber portion. In this scenario, future maintenance of the downstream structure could take place without major dewatering concerns. The plan included installation of a two-foot-thick reinforced concrete slab. The slab was to be structurally tied to the steel sheetpile by welding studs to the sheets, thus locking the sheetpile and concrete slab together into a water tight structural barrier. The new concrete apron was located approximately 15 ft upstream of the gate location. Concrete piers were designed with embedded steel gate guides and are able to handle the full hydraulic loading of the gates. The slab was designed to take full hydraulic loading and the load transferred from the piers and gates without any buttressing affect from the downstream wood crib piers.

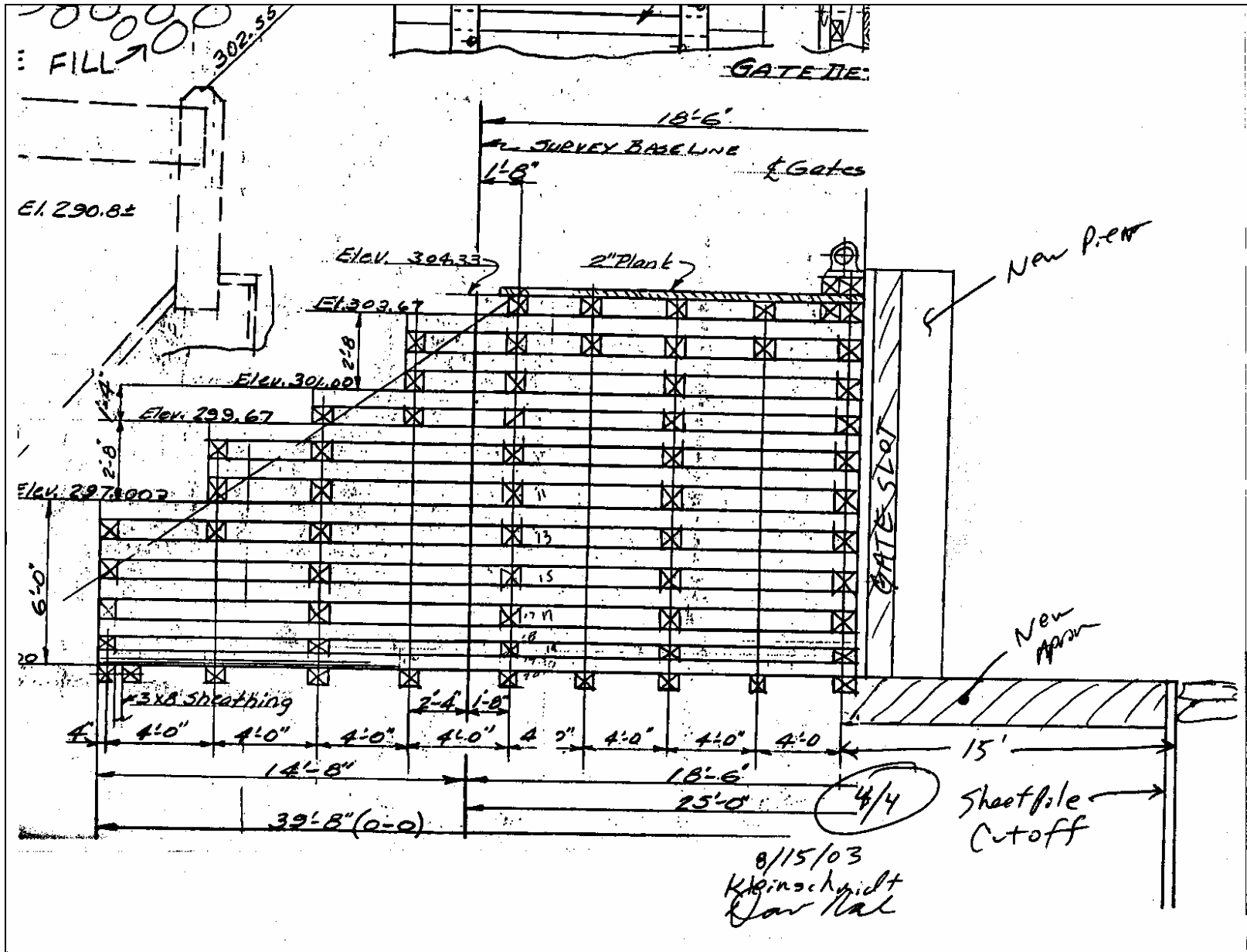
Once the Phase I cofferdam was installed and the flow could be transferred to the new gate structure, the Phase II cofferdam was installed and the gate structure razed and then rebuilt. All this work both in mobilization and design was done under emergency conditions and, as such, any method to expedite review, approval and construction was employed. For example, as you can see from sheets 2/4 and 4/4, hand markups of existing plans were used to transmit the design concept.

The sketches were developed one day after the event and faxed to the team for discussion. The design concept never changed from the original concept. Other than details and CAD drafting, you will see from the drawing developed there is not much difference between the conceptual and final product.



Sheet 2/4

FIGURE 3
 WEST BRANCH PRO
 PENC NO. 2018
**WEST GRAND
 PLAN VIEW**
 GEORGIA - PACIFIC CO



Sheet 4/4

This design concept had the unique benefit as the effectiveness of the water tightness could be tested before committing to it. By using a steel sheetpile cofferdam with sheets driven to refusal, it provided a good chance to seal the structure. It was anticipated that the real test would occur when the coffer was dewatered, as any trouble spots such as underflow or end run flow would be detected. The plan also required casting the concrete directly against the sheetpile and then cutting the steel sheets flush with the concrete apron, which assured that the integrity of the cutoff structure was maintained.

Construction

The project construction activities began almost immediately due to the emergency nature of the potential failure of the dam. Cianbro Corporation is credited with initiating work immediately. While on site Saturday discussing the plan and pace that had been started with Mr. Harold Kamara, Cianbro was already mobilizing a larger crane and steel sheetpile for the cofferdam, approximately two days from the onset of the problem. In fact, Cianbro Corporation was designing the details of the cofferdam and Kleinschmidt Associates was reviewing the design at the times the sheets were being driven on Monday the 18th.

The Phase I cofferdam was installed without major incident or changes required. The original plan called for flat sheets to be driven against the timber crib abutment for a distance of fifteen feet. As a result of difficulty in driving the sheets, they were flared away from the abutment and extended into the embankment. This realignment allowed for the sheets to be driven, providing a continuous cutoff on the east embankment. Once the cofferdam was dewatered, only minimal seepage was observed in the area providing assurance of an effective seal. Upon dewatering the coffer, it became apparent where some of the problems had developed. The vertical timber cutoff wall was very shallow and did not penetrate the alluvial material. It appeared the original construction only went down to the sub-grade and was built from a level granular surface up. Additionally, many areas between the planking had significant water wear from past leakage. It was possible to raze the entire crib apron and gate piers without incident. There was a considerable amount of leakage end running from the cofferdam closure at the west end, but this situation was adequately controlled for the Phase I work. A layer of stone was placed as a subgrade of the slab prior to placing plastic sheeting and subsequent reinforcement. Phase I was completed, including the proposed concrete apron and piers. The team felt confident that the gate five area had been replaced and the leakage was well under control.

Work proceeded on to the Phase II cofferdam by putting in a steel diaphragm wall and transferring flow to the new gate four and five area. Two difficulties developed in the Phase II coffer, the first being interlocking the sheets to the phase one coffer and sealing at the fishway side. This was resolved by installing a temporary gate in bay three, pulling the interlocking sheet and driving new sheets. The second area was much more challenging as there appeared to be a hole under the existing concrete wall. A number of sand bags were placed in the area with minimal success at reducing the leakage to an acceptable level. An alternate cofferdam closure plan was subsequently developed. This alternative consisted of entirely enclosing the gate structure and fishway within the cofferdam. This was one of the best decisions the team made. Upon dewatering the Phase II cofferdam, a huge void was found under the existing concrete training wall that separated the fishway from the gate structure.



Void under existing concrete training wall discovered during dewatering.
Note embedded sand bags.

The wall was completely removed and the concrete apron was placed up against the sheetpile cutoff wall. A new concrete training wall was poured on top of the apron, re-establishing the separation between the fishway and the gate structure.

It was determined that water entering beneath the concrete wall was the major contributor to the leakage at gate bay five. Water apparently had entered from one side of the gate structure and exited the opposite. The flow was passing under the apron by way of the open cribwork totally masking the source of the problem area.

The installation of a steel sheet cutoff across the entire gate and fishway structure essentially eliminated the future concern for piping beneath the gate structure. To aid in future observations and maintenance of the structure, two stand pipes were installed and an under drain discharge pipe. The standpipes will be used to monitor any uplift beneath the concrete gate apron that would indicate excessive underflow building uplift. The under drain discharge pipe exits on the downstream side of the gate structure and provides a visual observation of the leakage. The discharge pipe is a four inch PVC pipe that is only flowing partially full. Remember the underflow/leakage that we started with was eighteen inches deep over a width of nine feet, not to mention other bay leakage and pier leakage. As can be seen from the reduction in leakage down to a small weeper pipe, the success of this project speaks for itself.

It is worthy to note that leakage exiting timber crib structures can originate from sources far from the exit point. Careful investigation can help find many of the sources of leakage, but one has to be prepared for the unexpected. Making good decisions and not leaving any unknown to chance is the ultimate solution. Totally encompassing the existing structure within the cofferdam allowed the team to explore the entire structure and address unforeseen problem areas.

Conclusions

It would be an understatement to say that the success of the design of this project under emergency conditions was a team effort. Some examples of team work resulted in the owner, Domtar Industries, under the direction of Mr. Tim Lowe, on the very next day after the development of the emergency, accepting the situation and giving the go ahead for the design concept and construction. The efforts of Mr. Steve Strout of the owners staff for coordination of all aspects of the project and review of the design details and enhancing the design. Also, the PFMA facilitator, Mr. Bruce Brand, reviewed the design concept and details on August 22, 2003, after only receiving the design on August 18. Mr. Brand performed a structural analysis and made suggestions as to areas of the slab that may need additional reinforcement. His comments were directly applied to the constructed project.

Mr. Eugene Gall and his staff reviewed the design and construction plan and encouraged the team with positive feedback. Additionally, Mr. Harold Kamara was on site on Saturday, August 16 to conduct an assessment of the situation and relay his findings back to New York. The contractor, Cianbro Corporation, brought the equipment manpower and experience to this dynamic team.

The implementation of the PFMA process was very timely on this project and correctly identified a significant potential failure mode that was nearly tested. Timber crib structures all leak, but there comes a point that certain indicators become tell-tale signs of developing problems, such as excessive leakage and unexplained settlements. Emergency response teams with qualified team members given decision making power result in very successful projects. Even under emergency situations, one need not panic and positive environmental measures can be undertaken.



Completed Project

Acknowledgements

The authors would like to acknowledge that without a powerful team with the ability to make decisions, this dam very well could have failed with significant social environmental fallout. It is not possible to recognize all the individuals who had an impact to the success of this project without inadvertently omitting some. However, had it not been for Domtar Industries willing to do what was right, federal agencies expediting approval, Kleinschmidt Associates having the experience and resources to complete the design, and Cianbro Corporation, a highly respected and capable contractor, this could have been a very different outcome.