24-096

Downstream Improvements on Upstream Dams: An Owner's Perspective of a Paradigm Shift

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ABSTRACT

Mining companies have sharpened their refocus on their tailings management strategies in recent years. Mining companies with tailings storage facilities that use the upstream construction method have been challenged to track the evolution of industry standards, assess risks, revise design, and communicate design revisions with regulators. While many aspects of best practices and industry standards have evolved in recent years as an attribute of continual improvement, the controlling standard in the design of many upstream dams is understanding the foundational strengths of hydraulically deposited tailings. Following best practices and industry standards, Hibbing Taconite Company managed by Cleveland-Cliffs, began the re-evaluation of foundation strengths underlying a system of upstream dams at the company's iron ore mine tailings storage facility in northern Minnesota. Initial steps in the re-evaluation require reanalysis of design parameters and recommendations by the Engineer of Record to the Owner, which was followed by a series of meetings with the Technical Review Board to determine an initial path forward. Once a path forward and preliminary design parameters were determined, the Owner engaged with the State Dam Safety Engineer to discuss and seek approval of the plan. With continuous regulatory engagement throughout the process, further refinement of the design parameters for the hydraulically-placed tailings foundations underlying upstream dams began with field and lab geotechnical investigations. Following a review of risk assessments and trigger actions response plans, Hibbing Taconite revised its tailings storage facility operating plans and budget for the coming years. Based on the findings of the re-evaluation, reanalysis, and refinement of parameters, a paradigm shift was realized with the hydraulically placed tailings foundation strengths underlying the upstream system of dams. This paper explores the path that the Hibbing Taconite Company followed to understand the paradigm shift and construct downstream improvements. The plan involved tailings re-characterization, dam design revisions, operating plan reconciliation, budget revisions, wetland permitting, dam safety permit amendments, storm water prevention plans, borrow materials studies, new concrete decant structures and the pursuit to recognize and be consistent with industry standards.

INTRODUCTION

Cleveland-Cliffs, Inc. is the largest flat-rolled steel producer in North America. Founded in 1847 as an iron mine operator, Cleveland-Cliffs, Inc. also is the largest producer of iron ore pellets in North America. The Company is vertically integrated from raw materials from its Minnesota and Michigan mines, direct reduced iron, and ferrous scrap to primary steelmaking and downstream finishing, stamping, tooling, and tubing. Cleveland Cliffs, Inc. is the largest supplier of steel to the automotive industry in North America and serves a diverse range of markets due to its comprehensive offering of steel products. Cleveland Cliffs, Inc. is headquartered in Cleveland, Ohio with mining, steel and downstream manufacturing operations located across the United States and in Canada (Cleveland-Cliffs, Inc. 2023a). Cleveland-Cliffs, Inc. has a long history of safely operating tailings storage facilities and in 2022, was awarded the Midwest Regional Award in, and presented by the Association of State Dam Safety Officials. Cleveland-Cliffs, Inc. operates five tailings storage facilities, and has implemented proactive and conservative steps have been implemented to ensure the safety of these dams against potential failures. Through regular and rigorous review of the facilities, Cleveland-Cliffs, Inc. updated emergency action plans, reinforced thousands of feet of dam embankment and modified operations to reduce safety risks. Cliffs developed positive working relationships with state dam

safety staff in Michigan and Minnesota, keeping them apprised of operational status long-term planning and seeking feedback as necessary (Cleveland-Cliffs, Inc. 2023b).

This paper focuses on the steps Cleveland-Cliffs, Inc. navigated to reinforce a portion of the thousands of feet of dam embankment at the company's tailings storage facilities at Hibbing Taconite Company, located 5 miles north of Hibbing, Minnesota. Hibbing Taconite Company produced 5 million longs tons of iron ore pellets in 2022 (Cleveland-Cliffs, Inc. 2023a) and approximately 18 million long tons of tailings in 2022. The full site covers approximately 30,670 acres of which the tailings facility makes up approximately 6,500 acres as shown in Figure 1 on page 4. Approximately 13 miles of perimeter dams impound the tailings facility and 5 miles of interior dam allow for full tailings depositional utilization and improves access to areas for dust control activities. The perimeter tailings impoundment dams consist of earthen dams constructed over the life of the tailings storage facility from 1974 to the present. The tailings facility contains 3 active tailings impoundment cells and one reclaim water reservoir storing approximately 13,000 acre-feet of water dependent on climate conditions. The perimeter dams are constructed mechanically, and interior dams are constructed hydraulically with a coarse tailings handling (pumping) system. Hibbing Taconite Company utilizes upstream, offset upstream, centerline, and downstream methods of construction. Native clay cores and random downstream slope materials from a local borrow source were used in starter dam construction, which was downstream.: In the late 1980's, dam construction moved to upstream still using native materials from nearby borrow locations, and in the late 1990's, with the exhaustion on adequate native borrow materials, Hibbing Taconite Company began to use offset upstream construction. Tailings are deposited hydraulically using a coarse-tailings (+200 mesh) separating system, pump house and pipeline and the fine tailings (–200 mesh) flow via gravity from two launders from the concentrating portion of the iron processing facility allowing Hibbing Taconite to avoid fines tailings thickening and pumping. After the gravity deposition in tailings storage cells process water is decanted through an open channel concrete spillway in the West Area of the facility and through a decant drop structure in the East Area. The tailings process water treated in the tailings facility is reclaimed from a clear water (SD-3) Reservoir back to the plant through two 7-foot diameter pipes from an intake structure in the and reclaim pump house at approximately 120,000 gallons per minute as shown in Figure 1 on the next page.

The Hibbing Taconite Company tailings facility is in a broad, relatively flat-lying valley, situated north of the plant. The surface geology below the facility and at the toe of the perimeter dams mainly consists of lacustrine (clay), swamp (peat and muck), and glacial (primarily till and outwash sand) deposits underlain by bedrock. The bedrock generally consists of intrusive and extrusive igneous rocks of Upper Pre-Cambrian age, including granite and gneiss. Most of the bedrock is massive, although the upper portions are fractured. The degree of bedrock fracturing in the exposed portions of the rock is variable, depending on elevation. The glacial till consists primarily of fine-grained soils, but contains a wide range of gravel, cobbles, and boulders. The matrix is typically a reddish-brown, sandy silty clay of moderate plasticity.

A PARADIGM SHIFT

A theory which overhauled human understanding of the heavens was the heliocentric model, first proposed by Greek philosophers, but it was not until Nicolaus Copernicus presented the mathematical model in the sixteenth century that the world accepted this new understanding and a paradigm shift occurred. While it might be presumptive to compare humanity's understanding of the earth's revolution around the sun to a change in our mastery of hydraulically placed fine tailings as a foundation to upstream dam construction, for tailings and geotechnical engineers and the paradigm shift we have seen over the last five years it is evident. In 1962 Thomas Kuhn wrote that a paradigm shift is "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity," but that is simultaneously "sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve." (Kuhn 1962). When the Engineer of Record informs Dam Owner that undrained shear strength ratios for liquefaction in the fine tailings foundations below upstream dams might shift from a value of 0.11 to 0.05, a cohort of those that understand the importance of undrained shear strength ratios for liquefaction in upstream dam design all realize that a paradigm shift is in the making.

Lessons learned from tailings dam failures around the world drove the mining industry to review its standards and in the case of upstream tailings dam construction the understanding of foundational materials was intensely reviewed. While recent events have highlighted the phenomena of liquefaction, case studies from AECOM (2009) and ASDSO (2023) point to liquefaction case studies back into the 1970's. Tailings storage facilities and their management have gained attention through world events, and that attention has further elevated tailings management

Figure 1. Hibbing Taconite Tailings Storage Facility Site Map

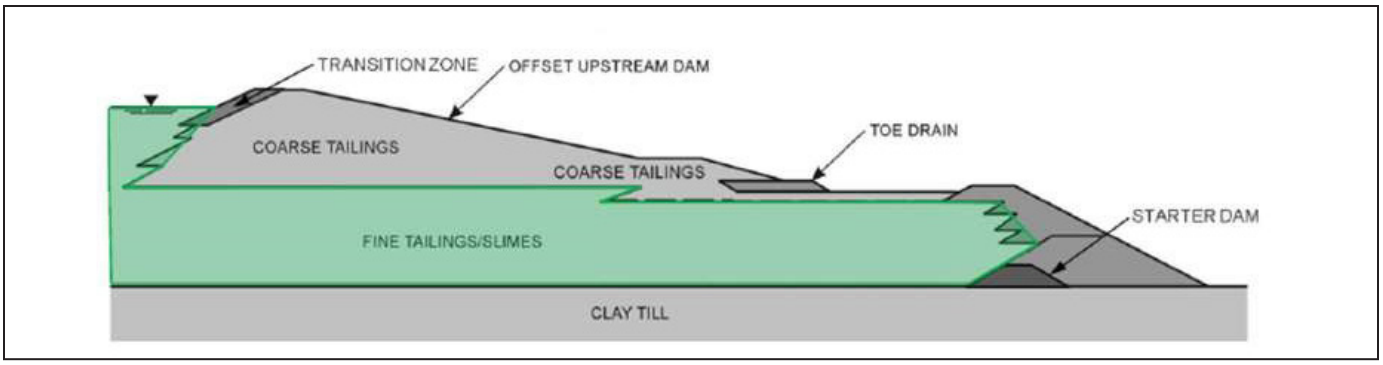

Figure 2. Hibbing Taconite Company Tailings Facility Impoundment Dam Typical Cross Section

prominence in every mining company's executive team. This paper focuses on how Cleveland-Cliffs, Inc. and Hibbing Taconite Company navigated the paradigm shift through internal planning and budgeting, regulatory engagement, evolving tailings guidance, and shifting industry standards.

Hibbing Taconite Company Tailings Storage Facility—Technical Review Board

In 2017, Cleveland-Cliffs, Inc. began an independent external peer review with the implementation of a technical review board at Hibbing Taconite Company. The Technical Review Board was made up of principal and project engineers from the Engineer of Record, two independent subject matter experts, and a Cleveland-Cliffs management representative and tailings engineering staff. The Technical Review Board began to review geotechnical dam design methodology used by the Engineer of Record for Hibbing Taconite Company. The Technical Review Board started by focusing on reviewing the controlling factor in dam design, which is the foundational characteristics of the offset upstream dam on hydraulically deposited fine tailings as highlighted in green in Figure 2.

In February of 2018 the initial findings of the technical review board indicated that the Hibbing Taconite Dam Design Methodology had some room for further refinement and verifications of methodology. Even though the dam design methodology was deemed to be defensible and prudent, The Technical Review Board for the Engineer of Record included suggestions to enhance the tailings facility design methodology. The report suggested looking further into the parameters and methods used to determine undrained shear strength ratio for liquefaction of the fine tailings foundation of the offset upstream perimeter dams. In November 2018 the Engineer of Record followed the guidance of the Technical Review Board findings and required a re-evaluation of the dam design at Hibbing Taconite Company. The re-evaluation of the dam design at Hibbing Taconite Company focused on more significant geotechnical investigation and confirming methods used to estimate the undrained shear strength of the fine tailings. During this process, tailings management gained a world-wide audience with the video of a January 2019 liquefaction failure of a tailings storage facility in Brazil. This event, accelerated and influenced the dam design re-evaluation path that was already underway at Hibbing Taconite Company.

Throughout 2019, the Technical Review Board continued to review the findings of geotechnical investigations, review new literature, and incorporate the subject matter expert's suggestions to determine an appropriate undrained shear strength ratio for liquefaction to be used in dam design. The variability of tailings, which range from slimes/clays to silts to sands, while considering dilative and contractive behaviors, all framed by the unique layering of those tailings through hydraulic deposition can make the determination of strength arduous and presents much uncertainty as to the representativeness of the estimate values. Interpretation of both laboratory and in-situ data, given the variability of tailings noted above, is onerous and time consuming. Given the timing of Hibbing Taconite Company's re-evaluation path relative to the Brazil tragedy the Technical Review Board, at the request of Cleveland Cliffs, decided to use a conservative worst case assumption for undrained shear strength ratio for liquefaction of 0.05. The alternatives analysis using the undrained shear strength ratio for liquefaction of 0.05 was undertaken in March 2019 and involved the alternatives noted in Table 1 and Figure 3.

In April 2019, the Technical Review Board selected Alternative C noted above and Cleveland-Cliffs, Inc. began budgeting and planning efforts for 2020 construction. During the remainder of 2019, the Technical Review Board continued review of the work being completed by the Engineer of Record to define an undrained shear strength ratio for liquefaction based on extensive laboratory

and field-testing efforts with over 18,000 data points from geotechnical testing programs at the Hibbing Taconite Tailings Facility. In fall 2021, the findings of the Engineer of Record were accepted by the Technical Review Board and to date at Hibbing Taconite Company Tailings Facility construction of downstream improvements are planned to last until 2025.

Regulatory Engagement

Cleveland-Cliffs, Inc. wanted to engage regulators regarding the dam design re-evaluation in a timely and transparent manner to facilitate potential permit modifications.

Table 1. Hibbing Taconite Company Tailings Facility Alternatives Analysis

Alternative	Description
Alternative A	Dam Design Revaluation Option A—Ground Improvements of Fine Tailings/Slimes Underlying the offset upstream dam.
Alternative B	Dam Design Revaluation Option B—Upstream Dam Construction
Alternative C	Dam Design Revaluation Option C—Downstream Dam Improvements
Alternative D	Modifications to Tailings Processing Considerations—Filtered Tailings (Dry Stacking)
Alternative E	Do nothing option.

Permitting the downstream improvements had three facets as shown in Table 2 below. The WCA Wetland Replacement Plan Application began with wetland delineation mapping during summer 2019. Wetland delineations were submitted to the Minnesota Department of Natural Resources (MDNR). MDNR followed-up with a field visit in September of 2019 with approval of the wetland delineation boundaries on January 2, 2020. During that process Hibbing Taconite worked on the WCA Wetland Replacement Plan. A pre-application meeting was held with the regulatory agencies listed in Table 2 in October 2019 with a follow-up call in November 2019. The Wetland Permit Application was submitted in January 2020 and approved in August 2020, at which time the first downstream improvement projects began immediately after permit approval. Lessons learned on wetland replacement plans include:

- Early engagement of agencies as the full process turned out to take approximately 14 months.
- Final design construction limits should be submitted with the wetland application to avoid dam design creep.
- The construction limits that are set with the submittal of the Wetland Application cannot be shifted with further design revisions without resubmittal.
- Before commencing construction clearly mark the construction limits and have a focused meeting with the contractor regarding working around and protecting the construction limits.

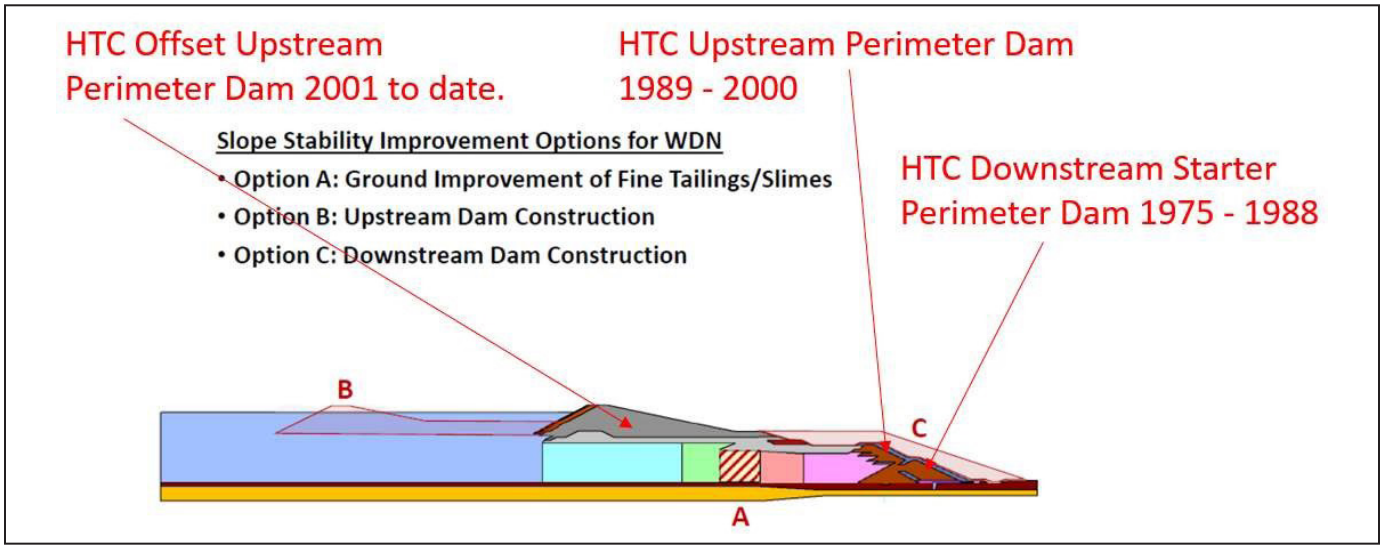

Figure 3. Hibbing Taconite Company Tailings Facility Alternatives Evaluation

Table 2. Hibbing Taconite Company Tailings Facility—Downstream Improvements Permitting Requirements

Permit Name	Regulatory Agencies Involved
WCA Wetland Replacement Plan Application	Minnesota Department of Natural Resources—Division of Lands and Minerals (for projects under a permit to mine) United States Army Corps of Engineers (Administration of federal clean water act) Minnesota Pollution Control Agency—401 Water Quality Certification.
Dam Safety Permit Amendment	Minnesota Department of Natural Resources—State Dam Safety Engineer
Permit to Mine Amendment	Minnesota Department of Natural Resources—Division of Lands and Minerals

from Cleveland-Cliffs, Inc. to meet with the Minnesota State Dam Safety Engineers Office. During the meeting, Cleveland-Cliffs explained the recommendations of the Technical Review Board to proceed with Alternative C—Downstream Improvements and to begin discussion on the dam safety permit amendment process. In September 2022, Cleveland-Cliffs, Inc. was recognized by the Association of State Dam Safety Officials Midwest Regional Award. One of the main reasons for the nomination by the Minnesota and Michigan State Dam Safety Engineers was the transparency that Cleveland-Cliffs, Inc. has shown in its communications with the dam safety regulators over the years. In 2019, Cleveland-Cliffs, Inc. was on the leading edge in discussions with dam safety regulators regarding the paradigm shift that the tailings industry was tackling. Figure 4 below shows a graphic used in the presentation to the State Dam Safety Engineer on July 24, 2019 to explain why the determination of undrained shear strength ratio for liquefaction of tailings was going to take time. Furthermore, the Cleveland-Cliffs team explained why conservative assumptions to be used in dam design by the Engineer of Record would be sufficient to begin construction before the revised

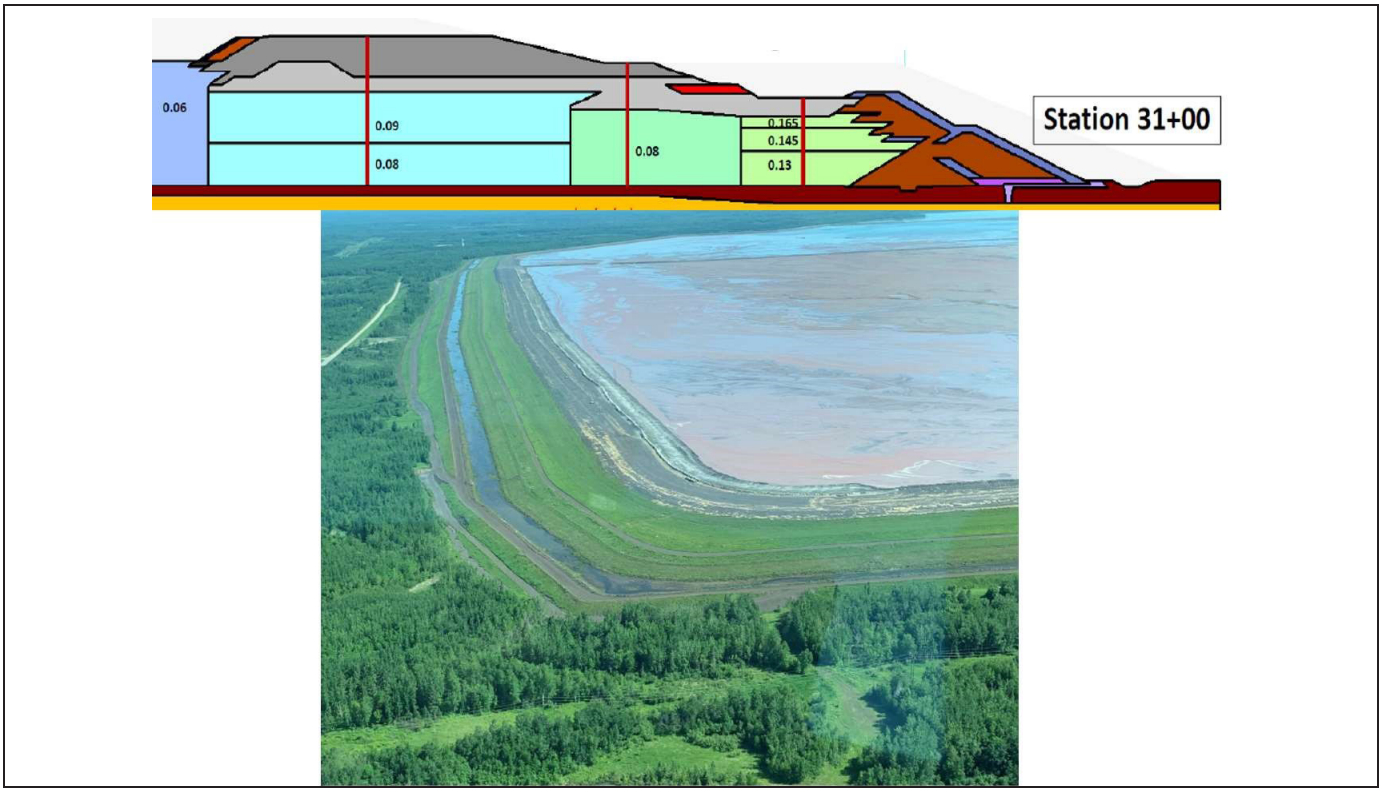

Figure 4. Hibbing Taconite Company Tailings Facility prior to downstream improvements

The Dam Safety Permit Amendment process began on July 24, 2019 with a trip to Saint Paul, MN by a group

undrained shear strength ratio for liquefaction of tailings at Hibbing Taconite was determined. That determination was reviewed and approved by the Technical Review Board in the fall 2021. Figure 4 aided in the communication of the many steps for the Engineer of Record to get to a defensible undrained shear strength ratio for liquefaction of tailings.

Finally, given the scale of the proposed downstream improvement project, and considering available constructions materials, construction rates and improvement work needed on 8 miles of upstream tailings impoundment dams a construction schedule was in order. A reasonable construction schedule that could be logistically achieved was prepared for and discussed with the State Dam Safety Engineer. Figure 5 is a map showing the downstream improvement plan schedule, which will be further discussed in the next section. The first dam safety permit amendment for the downstream improvements was issued on October 27, 2020.

Turning Multiple 300-Page Design Reports into a dam

A paradigm shift involving the undrained shear strength ratio for liquefaction of tailings is a difficult subject to explain, and when that paradigm shift means a very significant shift in the tailings facility operating plan, a very well thought out explanation should be prepared to ensure the dam owner fully understands the project need and budget appropriately.

Distilling a design report or multiple design reports into an operating plan that can be easily understood and accepted by a dam owner is a key first step in internal

Figure 5. Hibbing Taconite Company Tailings Facility Downstream Improvement Plan

Table 3. Hibbing Taconite Company Tailings Facility—2018 Operating Plan comparison to the 2019 Operating Plan

	2018 MCY	2019 MCY	2020 MCY	2021 MCY	2022 MCY	2023 MCY	2024 MCY	2025 MCY	2026 MCY	Total
2018 Operating Plan Total Movement	**1.97**	**1.47**	**1.85**	**2.082**	**1.24**	**1.322**	**1.65**	**1.302**	**0.87**	**13.756**
Subgrade Excavation										**0**
Coarse Tailings - Upstream Crest Raise	1.82	1.32	1.7	1.68	1.04	1.2	1.5	1.2	0.8	**12.26**
Coarse Tailings - Downstream Embankment Fill										**0**
Clay Core for Upstream Cutoff	0	0.05	0.05	0.15	0.05	0.02	0.05	0.05	0.02	**0.44**
Toe Drain and Filter Materials	0.1	0.05	0.05	0.2	0.1	0.05	0.05	0	0	**0.6**
Mine Rock - Rip Rap	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	**0.45**
Concrete Decant Structures				0.002		0.002		0.002		**0.006**
2019 Operating Plan Total Movement	**2.17**	**2.07**	**4.009**	**4.754**	**4.19**	**4.372**	**2.65**	**1.402**	**0.87**	**26.487**
Subgrade Excavation			0.4	0.2	0.4	0.1				**1.1**
Coarse Tailings - Upstream Crest Raise	2.02	1.32	0.5	0.5	1.04	1.2	2.1	1.2	0.8	**10.68**
Coarse Tailings - Downstream Embankment Fill		0.6	2.9	3.8	2.5	3	0.4	0.1		**13.3**
Clay Core for Upstream Cutoff	0	0.05	0.15	0.2	0.15	0.02	0.05	0.05	0.02	**0.69**
Toe Drain and Filter Materials	0.1									**0.1**
Mine Rock - Rip Rap	0.05	0.1	0.05	0.05	0.1	0.05	0.1	0.05	0.05	**0.6**
Concrete Decant Structures			0.009	0.004		0.002		0.002		**0.017**

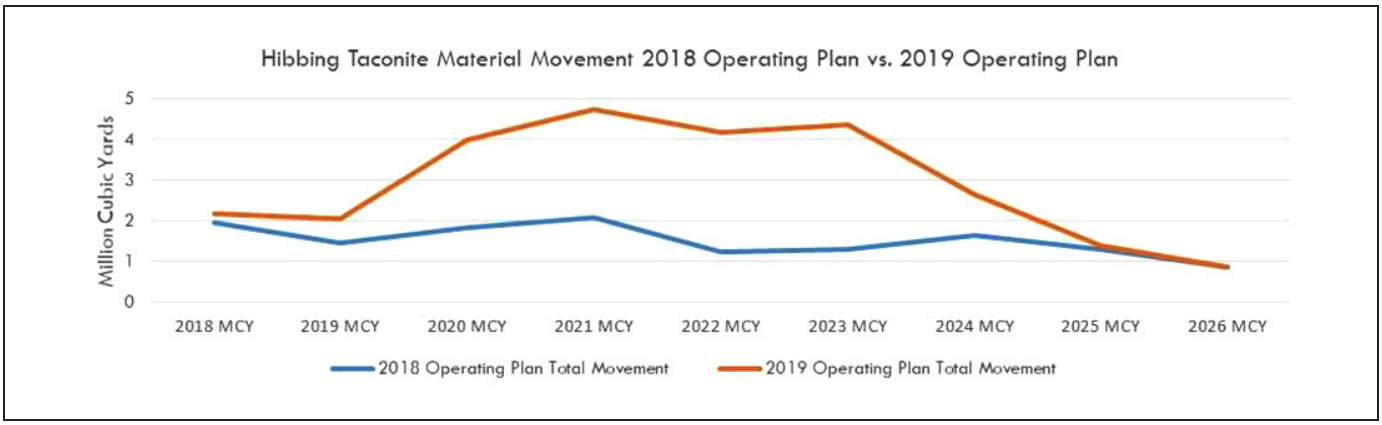

Figure 6. Hibbing Taconite Company Tailings Facility Operating Plan Comparison

alignment. The second step is to align a reasonable and pragmatic operating plan with the goals of the project, which in the case of Cleveland-Cliffs and Hibbing Taconite Company that goal is to operate an exceedingly safe tailings storage facility. To give the scale of shift that the downstream improvements inclusion into the operating plan presented is shown in Table 3 and Figure 6. As illustrated in the 2019 operating plan in Figure 6 the years 2020 to 2024 swelled by two to three times the 2018 operating plan. At Hibbing Taconite Company, the main dam construction materials are the coarse tailings (a well-graded sandy soil), which is well-suited for an impounding fine tailings, so the main constraint on construction rates was the supply of coarse tailings. The introduction of this paper notes that Hibbing Taconite Company produced approximately 18 million tons of tailings in 2022 of which 7.2 million tons are the coarse fraction. Of that 7.2 million tons, not all are available for dam construction, so the 2019 operating plan fit to that availability and what was logistically probable to be able to complete each year.

Table 4. Hibbing Taconite Company Tailings Facility—Downstream Improvement Embankment Volume compared to Undrained Shear Strength Ratio for Liquefaction

Undrained Shear Strength Ratio for Liquefaction	0.05	0.08	0.11
2019 Downstream Embankment Volume Estimate (MCY)	13.3	7.8	4.6

Table 4 compares the fill volumes required needed for downstream improvements based on the revised dam stability analysis using the initial conservative assumption of 0.05 for an undrained shear strength ratio for liquefaction used in 2019 planning and design. The significant variation

of embankment volumes in Table 4 needed additional explanation to achieve all the necessary company approvals. . An alternative method of communicating the project scope based on an undrained shear strength ratio for liquefaction was a significant lesson learned in this project. Today, Hibbing Taconite Company continues to work with the Technical Review Board to confirm that work of the Engineer of Record is defensible and that as the industry continues to evolve, Hibbing Taconite Company follows suit in its management of tailings.

CONCLUSION

Lessons Learned:

- Early engagement of regulators is key to a successful project.
- Construction limits and many other decisions made during preliminary design can be risky because those decisions are being made on assumptions of the final design.
- Transparency builds trust with stakeholders and regulators.
- Permitting takes time and iterations, early and transparent engagement is a key to successful permitting efforts.
- Prepare your explanations early, clearly, and suited to the audience.
- Concision is a key when preparing a project explanation.
- Conservative assumptions can be costly, as it was at Hibbing Taconite when an undrained shear strength ratio for liquefaction of 0.05 was assumed with the lack of other supporting data.

ACKNOWLEDGMENTS

The author would like to thank Cleveland-Cliffs, Inc. for the opportunity to present this paper.

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