Abstract

Located 500 km north of the Arctic Circle, the massive Mary River Iron mine project required an operating ore dock to annually ship 3.5 million tonnes of iron ore to world markets. The high latitude Arctic ore dock loaded its first bulk carrier on August 8, 2015 from the its record breaking -17.75 m deep water berth. The project was executed by a design-build team selected by the owner after it became apparent the traditional design-bid-build method could not achieve schedule and budget objectives. Major challenges facing the design-build team included -35 degree celcius temperatures, 24-hour darkness, remote logistics, compressed schedule and varying geotechnical site conditions. To minimize risk in this challenging environment, the design-build team redesigned most of the project with a major focus on modularization of components in the south and utilization of a land-based construction methods rather than reliance on a fleet of marine equipment.

Introduction

On August 8, 2015 the Federal Tiber bulk carrier departed the Milne Inlet Ore Dock located high above the Arctic Circle as shown in Fig. 1, having just been loaded with over 32,000 tonnes of the first export of high-grade iron ore destined for Nordenham, Germany. Just one year earlier this isolated site, accessible only during three brief ice-free shipping months, and was a bare stretch of Arctic wilderness coastline with only the hint of the beginnings of a world record-setting deep water port. At almost 71 degrees latitude, and a water depth of -17.75 m, the 22.5 m tall dock is the deepest water structure ever constructed at high latitudes. Designed to accommodate Post Panamax Class bulk carriers and to withstand the crushing forces of 2 m thick Arctic ice, the dock was engineered and constructed in under 17-months through the collaborative efforts of a design-build delivery method.
In addition to an accelerated schedule, the remoteness of the site, harsh Arctic weather conditions, and winter darkness pushed the design-build team to the limits. The project owner, and the entire economic success of their massive Mary River mining project hinged on the completion of the ore dock and readiness to begin shipping ore. Delivering the first iron ore to market was an absolute milestone. It represented the beginning of the revenue-generating phase for the project developers after spending dozens of years and hundreds of millions of dollars on exploration, permitting, and mine development. The design-build team consisting of a prime and pile driving contractor, an earth works contractor, and an engineering designer, were under intensive pressure to ensure this high latitude dock, shown in Fig. 2, was ready for business.
Background

Mary River Property is located on the north end of Baffin Island, Nunavut, Canada. The Mary River project first discovered in 1962, consists of 67% average grade of ore and requires only simple open pit blasting and crushing before shipping to markets. From the mine site, the ore is transported on an 85 KM tote road and stockpiled on a year-round basis adjacent to the Milne Inlet Ore Dock. The Milne Inlet Ore Dock project was conceived as an early revenue-generating phase when the original plans of building a rail and port on the south side of Baffin Island to Steensby Inlet was delayed due to costs. The Milne Inlet Port was designed to ship up to 3.5 MT of iron ore annually to European markets during the three-month open water season with the option to potentially ship during the winter shoulder seasons.

In the Arctic, ice loads are very large and gravity-based structures are used most commonly to resist the large ice crushing forces. Pile structures are generally not considered viable unless they are inclined to promote flexural failure of the ice. Inclined faces result in smaller loads compared to structures with vertical faces. Typical gravity-based structures used in the Arctic are vertical to allow ships to berth against and consist of rock filled, steel sheet pile structures and concrete caissons.

The Milne Inlet Port project required an aggressive budget and schedule to begin shipping ore as soon as possible to meet the financial objectives of the project. To ensure the best possible outcome and project objectives were met, a competitive tender for the construction of a new ore dock was released by the owner for qualified Arctic marine contractors in November, 2013.

Construction Requirements

The tender scope required a rock-filled gravity structure to comprise the ore dock, foundations for a 6,000 MTPH ship loader, and rock access causeway to be turned over to the ship loader installation contractor by February, 2015. The tender documents allowed pre-qualified contractors to choose a bid-build or design-build project delivery method. The design-bid-build option provided two fully designed gravity structure alternatives including; 1) Concrete caissons or, 2) Round cellular steel sheet pile structures. During the tender phase, however, the design-build team identified additional risks associated with the design-bid-build options. The risks with the design-bid-build alternatives are summarized below:

Marine Equipment.

The two alternatives would require marine equipment including tugs, material barges and barge-mounted cranes. Marine equipment at this high latitude is extremely expensive to mobilize to site and would need to over winter in the ice at the site.

Earthworks.

Filling the cellular sheet pile and concrete caissons with rock is a slow, tedious process because it must be staged from barges and placed with a clamshell bucket and/or conveyors inside the structure. The rock fill would come from a nearby upland quarry and required double handling because it must first be transferred from shore to barges then tendered a short distance offshore to fill the gravity cellular sheet pile or concrete caisson structures.
Concrete.
A large amount of cast-in-place concrete was required to construct the ship loader foundations. At an in-place cost of over $8,000 per cubic meter the concrete was not only expensive but is a complex and time consuming process and difficult to control quality particularly with the cold average temperatures.

Frozen Slurry Piles.
Sand slurry backfill used in permafrost soils creates a frozen bond between the pile and native soils. However, in transitional permafrost soils often found along the coastline, this method is difficult to perform when layers of thawed soil are encountered.

As an alternative the owner allowed contractors to choose a design-bid-build option. After pricing each design-bid-build option and weighing the associated risks with each option, the project team decided the best path forward was to select the design-build delivery method to minimize project risks and win the tender. The project required a complete redesign to specifically address each area of risk and focus on the comparative advantages of the design-build team. The project team developed and implemented a strategy that focused on their strengths and collective Arctic knowledge to mitigate the risks in the four key areas.

Marine Equipment.
Eliminate marine equipment and stage work from land on a rock work pad extended from shore. Mobilize cranes with enough boom that can safely reach the work area. Utilize a reinforced earth sheet pile design consisting of the U-shaped open ended sheet pile arrangement shown in Fig. 3. This type of structure is inherently more stable than the design-build alternatives because its aspect ratio can be increased simply by extending the tailwalls further back from the face. This type of sheet pile design makes it possible to construct from land without the need for a fleet of floating marine equipment.

Earthworks.
Eliminate the need for double handling rock fill and additional equipment such as barges, conveyors and/or clam shell buckets. Utilize instead conventional rock trucks, dozers and compactors staged from land to fill the open ended U-shaped sheet pile cells that are arranged to allow use of the standard equipment shown in Fig. 4. This method would also allow the earthworks contractor to place material much faster and to utilize equipment already on-site.
Concrete.

Eliminate the need for cast-in-place concrete that requires time-consuming form work and cold temperatures pouring and curing. Replace all cast-in-place concrete pile caps with prefabricated steel from southern fabrication shops that can be shipped to the site in large segments ready to install. The prefabricated steel pile cap sections would be welded to the steel pipe pile foundations at cut-off elevations. Replace cast-in-place conveyor building floor slab with precast panels.

Frozen Slurry Piles.

Eliminate frozen slurry piles and the extra steps required with this process and use thermal alternation installation method. This construction method uses pre-drilling and hot water to thermally alter the soils and conventional vibratory hammer to advance the pile into the hole. A freeze back bond provides the skin friction necessary to develop axial capacity.

All the above risk mitigation measures meant the design-build team had to redesign much of the original project during the tender process. After the redesign and the subsequent review process, the tender proposal was accepted by the owner and a contract awarded to the design-build team in February, 2014. The tender process took up valuable time while the project deadline remained fixed and it was up to the design-build team to follow through and execute with the time remaining.

Construction Execution

Construction equipment and materials were to be delivered to site by the owner with a sealift during the open water season. The sealift is only possible during three months of the year due to ice coverage and departs in late June from a consolidation hub in Valleyfield, Quebec. If the limited window to ship supplies is missed, air transport resupply is the only option for the remainder of the year. This meant duplicates and extras of everything for equipment and consumables would need to be on the sealift. From the time the design-build team was awarded the contract in February of 2014, there was only 4 short months to muster all the materials and equipment required for construction. Advanced planning and close coordination with all the suppliers and vendors was required to ensure it arrived in time to the consolidation hub.
Adding to the challenge of preparing for the sealift in only 4 months included equipment preparation and fabrication time not normally required in warmer climates. All the equipment required major alterations, including Arctic packages to allow it to operate in the average winter temperatures below -35 degrees Celsius. To minimize construction time onsite, any cast-in-place concrete foundations for the conveyor and ship loader were replaced with modularized steel units or precast concrete segments. All these items required design so the engineers worked an accelerated schedule. The design engineers integrated directly with the fabricators so design adjustments could be made to avoid any long lead items to ensure the schedule could be met. Due to the short lead time, fabrication work was spread between three different shops in Ontario and Quebec.

The most important part of the construction effort focused on a land-based method for driving the sheet pile for the dock, eliminating the risk and expense of marine equipment. This required cranes of sufficient size and capacity to loft, thread and drive over 900, 25 m flat sheet pile required to construct the dock face and tail walls. The equipment selected for the sheet pile installation included two Manitowoc 999 cranes each with a 210 MT capacity and a minimum 60 m long boom.

The cranes required a stable rock workpad to operate and stage sheet pile. The rock pad was constructed by the earthworks contractor by progressively pushing rock fill out from shore into progressively deeper water until the toe of slope intersected the –15 bathymetric contour. Based on a geotechnical slope stability analysis by the engineer, the crane set back on the rock fill pad was set at a minimum of 15 m from top of slope as shown in Fig. 5. The coarse rock fill used to construct the fill pad was blasted from a local quarry and comprised of maximum 6-8 cm rock diameter to allow the sheet pile tailwalls to penetrate into temporary slope of the rock pad. The toe of the slope was designed to not intercept with the face arc sheets to make pile driving easier.

Face arc and tail wall templates were installed before steel sheet pile for each cell could be driven. There were enough templates on site to construct six sheet pile cells at time. An arched template was used by the pile driving crews for the face arc and straight H-beams were used for the tail wall templates. Flexifloats were used by the crew as a work platform and to temporarily hold the template for final positioning until pin piles could be driven to secure the templates in place as shown in Fig. 6. The arc templates were left in position for temporary support of the sheet pile until rock fill could be placed. Specifications allowed partially filling of cells as soon as the sheet piles are installed for the cell immediately adjacent. At no time would cells be allowed to be fill any higher than 1.5 m higher than the adjacent cell to avoid bending the tail walls. The templates were moved once a cell had been stabilized with approximately 5-10 m thick layer of rock. During installation of the sheet pile dock, close coordination with the ship loader installation contractor was required to offload and stage all the pre-fabricated ship loader components. At times the site was very congested with work activity and staging of the ship loader components can be seen in Fig. 7.
Fig. 5 - Temporary rock workpad for cranes

Fig. 6 - Flexifloat work platform and sheet pile templates

Fig. 7 - Project status on September, 2014 with ship loader components (blue objects) staged on-site
The project required the installation of over 118 pipe piles, 61 to 91 cm diameter, that comprised the foundations for the 800 m long reclaim conveyor and the two ship loader towers. The piles located in the uplands installed in permafrost, used a thermal alteration process rather than the typical frozen slurry method. Major equipment for this operation included a 200 and 230 Yutong drill, equipped with an air-lift reverse circulation system and an auger with a with clean up bucket. Using the drill and auger attachment, a casing was installed in the top 1-2 m of the thawed active layer. Then with the drill air-lift system attachment, an undersized hole was drilled through the frozen ground for the full depth of each pile. Each hole was filled with hot water (65 to 100 degrees C) from a boiler and steam added as necessary to reheat the water. Specifications required the soils to be heated to a minimum -1 degree C isotherm for sand and gravel to facilitate driving with standard pile driving equipment. Thaw time ranged from 12 hours to up to 2 days depending on actual ground temperature, size of hole and soil types encountered. Freeze back temperatures were monitored by the engineer onsite with regular thermistor readings to ensure minimum ad freeze bond strength was achieved before the conveyor installation contractor was allowed to load up the foundations. Temperature data versus depth (whip lash curve) were plotted for a minimum of five test piles to develop a ground temperature profile over time. The results are presented in Fig. 8.

![Pile ground temperature profile](image)

Sheet pile driving for the dock was completed by November 1, 2014 and the earthworks contractor began placing the remainder of the rock backfill. The pile driving contractor had installed over 23,000 meters of flat steel sheet pile during the process. By November daylight hours were severely reduced and the extremely cold weather completely froze the sea in front of the newly finished sheet pile dock shown in Fig. 9. During final fill operations, to the extent possible, ice was removed from inside the completed cells before they were filled with rock. Any buried ice or snow mixed in with the rock fill is not considered a problem. Thaw consolidation does not cause any instability in the sheet pile dock
Once the fill behind the sheet pile dock was completed, the pile driving contractor installed the ship loader pipe pile foundations at the face of dock. These piles supported a majority of the weight of the ship loader and were installed 62 m below ground surface before capacity was reached as determined by normal procedures with the D-80 impact hammer. No permafrost soils were encountered at this offshore location. Completed ship loader foundations were handed over to the ship loader erection contractor by the beginning of February, 2015.

With the handover in February, 2015, the heavy ship loader foundations and sheet pile dock work were complete and the design-build team took a break until April, 2015. Tasks remaining included installing the face beam, mooring bollards, fenders and placing the scour protection rock in the berth box in front of the dock. In April, 2015, the ship loader installation contractor completed installing the large towers at the face of the dock and the sheet pile crew was remobilized to the site to complete the installation of the face beam on top of the sheet pile shown in Fig. 10. When the picture was taken in April, daylight is gaining fast and temperatures are warmer making it easier for the work crews. Also note the extent of ice bustle that attached itself to the steel sheet pile dock. The ice bustle is formed by tidal action and is extends from face of dock approximately 8 m, where an active zone has formed as seen in Fig. 10. The active zone is the intersection between the sheet ice moving up and down with the tide and the ice bustle bonded to the steel sheet pile dock.
In late June the ice in front of the dock had thawed enough to allow the dredge bucket to break through the ice. The final steps in completing the project required dredging in front of the dock to allow installation of the 1.5 m thick rock armour scour protection layer. Dredging in front of the dock was completed with the 210 MT crane operating immediately adjacent to the face of dock as shown in Fig. 11. Over 4,000 MT of scour protection rock was also staged on the dock face then placed with and excavator and spread to final elevation in the berth box with the dredge bucket and crane. The temporary loads during this final construction operation exceeded minimum operating surcharge design criteria by over 250% and served as a proof load to demonstrate robustness of the final in place reinforced earth sheet pile dock.
Construction Challenges

The pile driving contractor faced significant challenges during the installation of the steel sheet pile dock structure and the 91 cm diameter ship loader pile foundations. Because it is a design-build project, the project team owned these challenges and assumed responsibility for making any required adjustments to the design and/or construction methodology. This saved the owner significant time and money because both the design and construction expertise were wrapped into one contract.

During construction, the dock was exposed to open seas, including wind and waves. The 25 m long sheet pile proved difficult to thread in windy conditions and as a result, construction would be shut down on storm days. Waves had a potential to cause problems because the long sheet pile without any backfill have very little flexural strength. Additional bracing was essential and was not removed until the sheet pile were partially backfilled with rock fill. The sea bottom soil conditions also presented challenges for the construction of the sheet pile dock. During construction, the design-build team collected daily quality control instrumentation data and noted an anomaly in the data. The design-build team measured weaker than expected underlying foundation soil properties and immediately adjusted the construction methodology to adapt to the changed site conditions.

One of the biggest challenges of the project was achieving capacity of the 91 cm diameter pile. At the pile location for the ship loaders, there was no permafrost. With the weaker than expected soils, the piles were driven past the design depth and still not meeting capacity. The design-build team designed a plug plate so the piles would develop a plug to rely on both end bearing and skin friction. In spite of the challenges, the project was completed on time.

CONCLUSION

In spite of the challenges of this remote location and the Arctic extreme weather conditions, the design-build team delivered the deep water Milne Inlet Ore Dock on budget and on schedule in time for the first bulk carrier, the Federal Tiber, to load up with iron ore on August 8, 2015. From initial concept design development through completion of final construction the design-build team delivered the entire project in under 17 months as shown in Fig. 12. Major projects in the Arctic require a high degree of specialization and experience and the design-build method of project delivery allowed design and construction professionals to work together effectively. During the tender process, the design-build team quickly recognized the risks associated with the original design options that required marine equipment and implemented a much improved strategy to utilize a reinforced earth steel structure that allowed the construction to be staged from a stable rock workpad. Streamlining project delivery through a single design-build contract transformed the relationship between engineers and contractors into a partnership, which fostered collaboration, teamwork and out of the box thinking that resulted in a successful project.
Fig. 12 - Final completed ore dock and ship loader

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ADF Group- Steel foundations and pedestals for reclaim conveyor
BPDL- Pre-cast concrete for conveyor drive house