Concrete Headframe Supported on a ‘Bridge’

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ABSTRACT

Two options exist in regards to the headframe when designing a blind sinking operation: temporary headframe, replaced with a permanent headframe at a later date, or a multifunctional headframe that is a permanent headframe modified for sinking. Upon reviewing the two headframe options, it was determined that the multifunctional headframe option suited the construction schedule, sinking requirements, the overall project changeover schedule and the permanent friction hoist operation. The challenge with this decision laid in the design of the foundation system for the headframe as the sinking effort required the ground to be artificially frozen. The solution was to build a ‘bridge’ spanning the frozen zone and construct the multifunctional headframe, used for both shaft sinking and service access to the mine on this bridge. The bridge, which also functions as the headframe foundation, consists of four, deep concrete beams that span 30 meters and support a total weight of the slipformed concrete headframe of 9,500 tonnes. This paper will describe the challenges and details associated with bridging the frozen ground, and discuss other headframe elements including; steel plated deflection sheave floor acting as a structural diaphragm, an equipment floor, friction hoist installation during sinking operation, and repurposing of sinking rope openings.

KEYWORDS

Bridge foundation, Slipform headframe, Friction hoist, Sinking, Service headframe.

INTRODUCTION

In an effort to expand a current mining plant, a plan was developed to construct a service shaft closer to the new mine workings and convert the existing service shaft to a production shaft at the Potash Corporation of Saskatchewan Inc. Rocanville Potash mine in southeast Saskatchewan. The new service shaft required a headframe to support the operational requirements. The service headframe is an integral part of the mining infrastructure as it houses the tower mounted hoisting plant (hoist, deflection sheave, hoist controls, power distribution, etc.), as well as, the supporting infrastructure required to transport personnel and materials underground for operation and maintenance of the mine.

The mining plant expansion effort required a significant amount of capital investment over the 7 year construction period. Therefore, the project team deemed a reduced schedule as being a critical project objective. Furthermore, the shaft was being sunk through approximately 600 m of poor ground, which required the ground to be frozen to control the water present.

In order to maintain the construction schedule, a substantial effort was put forward by the engineers to design a headframe that could withstand the freeze-thaw cycle of the ground beneath.

HEADFRAME SELECTION (SINKING VS. MULTIFUNCTIONAL)

Based on the borehole data and historical shaft sinking logs from other sites in the area, a conventional blind sinking method was agreed upon, and therefore, two headframe options exist. The first option is to construct a temporary steel headframe to be used for sinking only then removed for the construction of the permanent headframe. The second option is to construct the multifunctional headframe that would be outfitted to sink the shaft, and later converted or changed over to the permanent service headframe.
The temporary headframe option is usually completed using a steel framed structure, which has the primary advantages of being quick to build and can be easily modified by the shaft sinker to accommodate changes to sinking support requirements. Often it is a requirement to complete rework of the structure to accommodate various sinking provisions, and since the structure is to be removed after sinking, the contractor may complete the rework without concern of the long term effects to the future operations. An additional benefit to the temporary steel headframe is that the initial investment is the lower and sinking can commence quicker. This is the most common option for shafts that involve ground freezing when sinking, because the foundation system can be simplified as frost heave issues do not exist.

The multifunctional headframe option is a more robust structure due to the design life in comparison to the temporary headframe. Thus will take longer to construct, and modifications during sinking will either be present for the life of the structure or remediation will be required. Despite the drawbacks, the advantage is that once sinking operations are completed, the changeover of the headframe to the end use set-up can be completed much quicker.

Upon reviewing the options, the multifunctional headframe option was selected based primarily on the project schedule. As the ground was being frozen to permit safe sinking of the shaft, this allowed additional front end time for the permanent structure to be constructed including the complex foundation system. The concept worked well for this project as similar height headframes would be required for both sinking and for permanent headframe. For this project the sinking operation actually governed the headframe height. The friction hoist, located at the upper level of the headframe, was installed while sinking operations continued, which reduced the changeover time.

**MULTIFUNCTIONAL HEADFRAME**

This section will provide background on the layout and describe the components of the multifunctional headframe.

The challenge of selecting a multifunctional headframe option, was designing the structure to support the varying conditions that exist with the dynamic nature of the structure. Lateral conveyance clearances are an important design consideration and are required to keep the conveyances away from the supporting steel tower but need to be minimal for effective operation. The challenge becomes even greater as two very different operations are being completed in the same structure. Therefore, at the initial design phase, many parameters had to be evaluated to ensure the facility would function well during all stages of the design life including sinking, changeover and service (refer to figure 1).
This blind sinking headframe followed a similar arrangement to a production headframe: the ground level hoist house (contains double drum hoist), winch house (contains the Galloway or sinking stage winches), sheave deck, dump, collar level access and safety doors. The height of the headframe was dictated by the sinking bucket clearances as these were greater than the permanent service cage clearance requirements. The sheave deck was the same level as the permanent deflection sheave level and was designed to accommodate both arrangements with minimal changeover time. The internal headframe structure was designed to incorporate as much of the permanent steel as possible to also minimize the changeover time after sinking. The temporary sinking steel was colour coded to facilitate the ease of identifying members to be removed. Much of the tertiary permanent infrastructure; enclosure panels, operators room, piping and permanent power, was omitted during fit up to facilitate a quicker sinking start up.

Upon completing the shaft sinking, the headframe was changed over to a service headframe. The changeover process required the removal of all sinking steel, chutes, buckets, monorails and safety doors and the installation of remaining permanent infrastructure. Safety bulkheads were designed to ensure the changeover would be completed as safely as possible. The structure was also to be used to install ropes and chair the conveyances for final outfitting of the hoisting plant. Extensive planning was employed and reviewed to ensure the safest most effective procedure was developed. Safety was always the number one consideration for all facets of design, construction and commissioning.

The changeover included repurposing the sinking rope openings located directly above the deflection floor. One of the larger openings was used for a door to access the emergency egress ladder way found on the exterior of the headframe. Several openings were utilized for HVAC ducting as the upper portion of the headframe was pressurized to ensure air does not contaminate the hoist.

After changeover was completed, the structure was in the end use configuration. The end use structure was a service headframe for the transportation of personnel and materials to the underground workings of the mine, and was constructed using slipformed concrete.
techniques as described in this paper. The structure located over the 6 m diameter shaft had a total self-weight of 9,500 tonnes, a height of 65 m, and a footprint of 14 m by 16 m inside plan dimensions.

The headframe has three primary elevated levels; hoist floor, mechanical / electrical floor and the deflection floor. The deflection floor serves a dual purpose; to support the sinking sheaves during sinking and the multirope service hoist deflection sheave. The sheave deck was designed as a structural diaphragm to support the great differential of loads imparted on this level. There were six sinking ropes with head and deflection sheaves at a variety of different angles. To aid in the placement and functionality of the sheave stools, a metal floor (diaphragm) was designed so the stools could be welded to the floor. A concrete floor structure was not a viable option as supporting the sheaves with cast in place anchors or post installed anchors required substantial slab thickness and placement challenges that would result in schedule impact.

There are two lower headframe levels; collar and sub-collar floors. The material handling level occurs on the collar floor, located at grade level, where two large overhead doors allow access for large machinery including loaders, forklifts, and transport trucks. The collar floor was designed to be a transfer point for materials to be shipped underground. The sub-collar is located below grade and provides personnel access to the shaft, as well as, the ventilation interface to the shaft. The headframe houses the tower mounted friction hoist to power a double deck cage capable of carrying 24 personnel per deck. The cage also has an available payload of 12,000 kg per deck or 24,000 kg of suspended load within the cage from the upper draw head (draw bar) (refer to figure 2, service stage layout).

**Figure 2. Headframe cross sections at service stage with components labeled**

**FOUNDATION**

As freezing the ground was a requirement for sinking the shaft, the foundation system needed to be protected from the freeze-thaw effects to safely support the structure.
The ground was frozen by a 12 m diameter freeze piping arrangement to build a sufficient freeze wall in order to support the 6 m diameter shaft sinking operations. The freeze affected a very large area causing the headframe foundation to be located outside the footprint of the structure, including all piling and most of the pile caps. Having the foundation piles isolated by distance was one measure incorporated in the design, but additional protection was provided by installing vertical pipes containing heated liquid between the freeze tubes and the vertical pile system (refer to figure 3).

*Figure 3. Headframe pile caps*

The headframe piling system consisted of 52, 0.91 m diameter by 22 m long concrete friction piles. The deep pile caps founded in the four corners of the structure and top of caps were located 6.6 m below grade level. The entire headframe is supported on eight total points of support located outside the footprint of the headframe with spacing between support points of 30 m east–west and 23 m north–south. The piling layout in each cap was laid out in a manner to evenly distribute the loading.

**FOUNDATION BEAMS / THE ‘BRIDGE’**

In order to transfer the loads of the headframe to the pile caps located outside the footprint of the headframe, deep concrete beams were utilized known as the ‘bridge’. These beams essentially bridge the frozen ground.

With such a significant loading criteria, every aspect of the bridge beams needed to be large. The four beams support the 9,500 tonne headframe and transfer the loading to the pile caps. This design produced varying concrete beam depths of up to 11.6 m and the pile cap layout created beam spans of up to 30 m (refer to figure 4). The beam depths were governed by openings in the headframe, which were found in all four walls. The openings were laid out such that the deeper beams could be placed on the long span sides (30 m) of the headframe. Since the shear span depth ratio (a/d) were below one, the foundation beams would behave as deep beams. As permitted by the concrete code, the design of the beams was completed using the strut-and-tie model.
The force distribution between the upper concrete headframe and the foundation beams first needed evaluation. Three-dimensional finite element analysis (FEA) plate models of the walls were completed to determine the force distribution to the foundation and around the large openings that exist close to the transfer level. These openings include the overhead doors, tunnels, and sinking dump openings. The models showed results similar to these expected with the forces funneling toward the edges of the headframe and toward the support (refer to figure 5).
These forces were then applied to a model that could accurately represent how the loading would be shared between the four beams in a given load combination, as two of the beams are 6.6 m deep and the other two beams are 11.6 m deep. Once the force distribution was established, the forces were placed in the strut-and-tie model.

The strut-and-tie model was developed and the internal force distribution was determined. Concrete stresses were checked to ensure they were below the allowable code criteria, and reinforcing steel was placed in the tension tie regions. The analysis yielded a maximum factored tie force of 21,500 kN, equivalent to the breaking strength of strength of approximately nine – 2” diameter full locked coil ropes.

Not only were the beams subjected to large vertical forces, but they were also designed to resist lateral forces from soil and ground water pressure as the beams are based at 6.6 m below grade in a region of a high water table. The lateral pressures were transferred by the walls to the concrete sub-collar and collar floor slabs. With significantly sized vehicles required to enter the headframe, the vehicle surcharge pressures placed significant lateral forces on the structure as well. The vehicle loading was taken into consideration by amplifying the lateral soil pressures in accordance with code procedures. Ideally, the wall thickness of the foundation would match that of the headframe that was to be constructed above by slipforming. However, the thickness of the beam/walls needed to be larger as dictated by both the lateral pressures and the area required to place the large amount of reinforcing in the primary tension ties at the bottom.

Due to the size of the beams it was evident conventional construction techniques would need to be modified in order to construct the structure.

DISCUSSION

Construction Issues

Due to extensive reinforcing and the larger thickness of the foundation walls, the project team decided that the reinforcing was too complex to slipform and therefore the slipform concrete walls would begin above the foundation walls. Therefore, the foundation beams were selected to be fixed formed. The original design intent was to have the concrete beams placed continuously, however, the height and layout of the concrete beams was too great due to forming restrictions even with the specialty forming system employed. The forming system used form-ties that tied the walls of the forms together in order to keep the forces associated with pouring
concrete internal within the forming system, and thus negating the requirement for lateral bracing. The forming system came in modular units that could be connected for quicker construction.

The use of self-consolidating, self-leveling concrete was chosen due to the height of concrete placement and dense placement of reinforcing steel. Injection ports in the side walls of the forming system allowed the concrete to be pumped into place. Many ports within the form system allowed for the concrete to be placed relatively close to its final location, and kept the horizontal travel distance of the concrete to a minimum.

The contractor requested to backfill adjacent the foundation walls prior to placement of the collar and sub-collar floor slabs; however, as indicated previously the walls distribute the backfill pressures to the floors and thus this was not acceptable. This meant the contractor would need to commence the slipping operations from 11 m above grade, the first time this contractor has begun a slipform operation from above grade level. Slipforming at elevation caused several issues; the most prevalent was access. The contractor installed temporary scaffolding, and a work platform at the base of the slipform operations around the perimeter to provide safe access to the slipforming operations.

Concrete Durability Requirements

Due to the importance of the foundation beams, protection measures were implemented in the design including increased requirements associated with class of concrete, permeability and cathodic protection.

The potentially hostile environment created by the mining and processing of potash resulted in a relatively high class of concrete being used to ensure no concrete quality issues exist in the future.

Very stringent concrete permeability requirements were specified for this project for two primary reasons: protection of the foundation beams and prevention of ground water entering the headframe. A key requirement of the project was to keep the shaft dry and thus to prevent ground water from entering into the shaft. To prevent water entering the shaft via the sub-collar (foundation) walls, the following measures were implemented: the concrete specified was a more stringent concrete permeability and to limit cracking additional concrete reinforcing steel was placed above the required strength level. Additionally, to limit potential water infiltration issues, a waterproofing membrane was placed around the perimeter of the exterior walls below grade for another level of protection.

A cathodic protection system was also installed to protect the reinforcing from potential corrosion. The selected system was an anode mesh grouted to the exterior of the headframe walls.

Headframe Material Selection

The headframe construction material selection is an important consideration, and there are two primary choices; concrete or steel. The concrete headframe was selected based on a concentrated construction schedule, a more robust structural system, a reduced headframe complex footprint and structural durability. These are some of the key reasons laid out in full in the ‘Headframe Design Selection – Steel vs Concrete’ paper (Butler and Schnyderberg, 1981). Once selecting concrete as a material, the optimal choice for a construction method was slipforming.

Concrete affords a more robust structural system in comparison to a steel headframe as concrete is very efficient at resisting and damping the loads imparted by the hoisting system. It also is an efficient system for resisting lateral loading in any direction. This is a great advantage as the headframe is designed for two primary stages; sinking stage and service stage. During the sinking stage, the winches and hoist powering the Galloway and the sinking buckets are ground mounted, and the sheaves are affixed to the deflection floor of the headframe. The sinking rope loading condition imparts significant lateral loads on the headframe. During the service stage, the tower mounted friction hoist is operational and though the system does not have significant lateral loads; the system imparts significant vertical loading.

Based on our experience as we have been associated with the design and construction of many slipformed concrete headframes in the past, including designing four within a three year period, we expected this was another area where schedule could be compressed. The remaining portion of concrete above the foundation beams was 53 m high, and was slipform constructed in only nine days (refer to figure 6).
<Figure 6. Headframe during sinking stage>

**Hoist Installation during Sinking**

A significant amount of time is required to install and pre-commission a friction hoist. Since the sinking did not need to stop for the install or pre-commissioning of the hoist, the project schedule was again compressed. In addition, the headframe was an excellent storage location for the hoist as it reduced the fees associated with storage, and was ready immediately when required.

The equipment floor is found between the hoist and deflection floors, and the floor’s end use is to support mechanical and electrical equipment associated with the hoisting plant. During sinking the floor was used as a bulkhead to protect the personnel involved in sinking while hoist installation occurred. Additional steel and timber was placed on the floor in order to function as a bulkhead; however, the majority of the elements were already installed.

**CONCLUSIONS**

For this project, based on the aggressive construction schedule, it was determined that the permanent headframe would be constructed initially and used to support the shaft sinking effort as well as the end use condition.

The project evolution resulted in an innovative solution of supporting a 9,500 tonne concrete headframe on a ‘bridge’ to achieve the projects primary objective of an expedited schedule. It is felt that by designing the headframe in this unique way, the overall construction schedule was reduced.
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