Conversion of a Service Shaft to a Production Shaft

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ABSTRACT

Traditionally mining headframes are constructed over the mine shaft to facilitate hoisting, provide head cover, facilitate safe access to the shaft and in some cases, to house a tower mounted friction hoist. In an effort to increase production and minimize down time, schedule, capital and construction costs, an approach was conceived to convert an existing service shaft into a production shaft. To better streamline the conversion process, a two phased approach was developed for the surface conversion. First, a penthouse would be constructed over the existing operational headframe and outfitted with a pre-commissioned hoisting plant. Second, the existing service headframe would be demolished and replaced with a new modular production headframe complex.

Designing the 107 m tall penthouse over the operating service headframe allowed continued access to the mine while providing the permanent infrastructure to install the hoist, one of the largest tower mounted friction hoists in the world.

Phase two involved removal of the existing service headframe infrastructure, erection of the new production headframe and interfacing the constructed penthouse. In an effort to minimize the construction time, an early works program was developed and a modular system was designed to facilitate construction from the top down.

This paper will describe the design challenges encountered for the penthouse and the modular headframe design and provide insight into the solutions developed and implemented.

KEYWORDS

Shaft conversion, Friction hoist, Penthouse, Modular headframe.

INTRODUCTION

In an effort to increase production and expand the current mining development, 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 conversion of a service shaft to a production shaft was a sizable endeavor and required extensive planning, creativity and teamwork to complete this task safely. The superstructure was divided into three parts: the foundations, the penthouse structure and the headframe structure. This paper will explore the design approach to this superstructure.

PROJECT OVERVIEW

All competent superstructures begin with a stable foundation and given that this structure houses one of the largest hoisting plants in the world and stretches 107 m (350 ft) high, substantial loads need to be supported. Adding to the challenge of supporting the largest steel headframe in the world was the limited foundation types governed by the reduced ground capacity. Typically, the headframe is a stick built structure from the ground up, but this approach required full access to the shaft and surrounding area, as well as immediate removal of the existing service headframe. The removal of the service headframe would result in the extended closure of the service headframe limiting access to the mining operation. An alternative approach was required to allow as much conversion work to be
completed without affecting or impacting the existing access to the mine, thus allowing mining operations to continue. A two phased approach was developed to allow a structure to be constructed around and over the existing headframe. In the first phase this structure, known as a penthouse, was constructed and the hoisting plant was installed with minimal disruption to the existing operations. The next phase was the construction of the lower headframe tower in modules, then moving the preassembled tower into position after the existing headframe was removed. This approach greatly reduced the installation schedule, but required extensive planning and design considerations to minimize constructability issues (see figure 1).

DESIGN CRITERIA

There were many design, operational and construction requirements for a project of this magnitude and establishing these criteria was the most important part of this design. A brief summary of the main design criteria for the conversion project was:

- The existing 5 m (16 ft) diameter composite lined service shaft was to be stripped and repurposed.
- The preferred minimum operating clearances to fixed obstacles were 450 mm on rope guides mid shaft, and 150 mm on rope guide in headframe and shaft steel and 75 mm on fixed guides.
- The hoist was a 6 m diameter drum with a 10,000 kW motor.
- The hoisting production rate was 1680 metric tonnes / hour.
- The skips were 46,000 kg (50 ton) payload Sala type with an operating speed of 18.3 m/s (3,600 ft/min).
- The conveyances were rope guided in the shaft and fixed guided at the dump and loadout.
- The design was based on relevant Canadian and Saskatchewan codes.

Once the design criteria were established, operational flow sheets were developed identifying the required elevations and footprint for conveyance clearances through the rope and fixed guided areas, the dump lip, the surge bins. As well, the operational clearances above the dump lip, the arresting distances, catch gear and crash elevation, deflection sheave and finally the friction hoist were established. In completing the clearance diagram, preliminary layouts were developed to maintain the operational clearances required to operate
the existing headframe and mine. After client had approved the general arrangement drawings and preliminary design, the penthouse and headframe final designs were initiated (see figure 2).

**Figure 2. Conversion headframe project**

**FOUNDATION**

Though the foundations were the first elements to be constructed, there was substantial structural design required to establish all the loading and reactions. A finite element analysis model was created and a table listing all the loads and reactions was developed capturing all the possible iterations and combinations. This evaluation revealed that uplift load conditions occurred during wind events and the bearing loading conditions occurred during a variety of environmental and operational events: static (dead) loads including the self-weight of the structure, the tower mounted hoisting plant and the guide ropes, and the transient loads including live, wind, hoisting, and rope breaking. The penthouse loading would be transferred through six legs and two braces, requiring eight discrete foundations with an allowable differential settlement less than 20 mm. With the penthouse foundation design criteria established the next stage was to consider the foundation system type.
Developing a foundation system design for this site was particularly challenging as there was a narrow band of competent ground sandwiched between glacial till above and a water bearing stratum below. Expanded base piles were the geotechnical engineer’s recommended system to transfer loading into the glacial till type soil. The expanded base system is an end bearing shallow pile with a reinforced shaft that supports both uplift and end bearing loading. The expanded base was formed by placing a specified amount of dry mix concrete and employing a specified amount of energy into the volume to force the material to expand and consolidate the supporting stratum. The number of piles could have been reduced if the pile caps could be tied together thus sharing the lateral loading, however the construction of these tie beams would have greatly disrupted operations, so this option was discarded. As a result, four main legs contained 30 piles, the two secondary legs contained 6 piles and the two braced contained 2 piles (see figure 3). All were constructed without compromising the daily mining operations. The typical pile was a 600 mm diameter reinforced shaft with a shaft length of 4.5 m to ensure there was bearing in the competent ground. The piles were tied into the pile caps through a lap slice between the pile and the cap reinforcing (see figure 4).
The pile caps were reinforced at the top and bottom to allow for the penthouse loading to be transferred from the leg, through the support piers, which contained substantial sized anchors and shear keys, to the pile groupings. The six larger pile caps were 2.5 m deep with a total volume of 292 m$^3$/cap, and the two smaller caps were 2 m deep with a total volume of 48.5 m$^3$/cap. The top of pile caps were constructed flush with grade to conform to the site water management plan and to allow for better, safe site access around the structure. The penthouse foundation system was designed to allow construction to occur without interfering with existing site structures and services.

The headframe foundation design required additional design consideration as many of the new headframe columns were within the confines of the existing headframe. A construction plan, known as ‘the early works program’, was developed to allow as much of the construction to be performed prior to removal of the existing headframe tower. The operators / power room to the north and part of the west collar house foundation was constructed, thus greatly reducing construction schedule. The west collar house was also removed to allow access to construct the new collar house and headframe to the west of the shaft. The bin house foundation was also outside the existing headframe envelope so these foundations were also constructed prior to phase 2. Constraints similar to the penthouse did not exist in the construction of the headframe foundation; therefore, tie beams were employed into the design to better distribute load and reduce the number of expanded base piles required. Eighty-nine piles were designed with a variety of cap sizes and configurations to meet the loading criteria. Unlike the penthouse caps located close to surface, there were three pile caps located within the headframe basement area, known as the subcollar and these caps were set 3 m below grade to maintain subcollar accessibility (see figure 5).
PENTHOUSE STRUCTURE

The penthouse building was an insulated steel structure that contained the new tower mounted friction hoisting plant. The hoisting plant includes the friction hoist, the deflection sheaves, rope suspension glands (for a rope guided conveyance system), the auxiliary hoisting equipment (drives, transformers, controls, brakes, bearing lube units, drive cooling, etc.), hoist control console. It also included the supporting infrastructure; including overhead crane, monorails and trolleys, fire protection, fire detection, heating and ventilation systems, power distribution, building electrical services, and the elevator machine room. However, before the penthouse could be constructed, the support legs had to be erected.

Though the hoist floor surface area needed to be moderate in size, for installation and maintenance, the penthouse area was increased to keep the support legs as vertical as possible and to allow clearance around the existing headframe. This approach was possible for three sides of the structure, however the fourth side required the lower support steel to cross planes with the exiting service headframe support legs, thus the steel was intertwined. A three dimensional model was created for both the existing and new structures in order to ensure the structures had adequate installation and operational clearances. This model was initially created utilizing existing drawings, and when it became known that the clearances were within 50 mm, it was decided to survey the critical regions of the existing structure and establish the shaft centerline datum. The model was updated with the survey data and the new penthouse support structure was redesigned to maintain a minimum of 250 mm installation clearance (see figure 6).
As previously stated the penthouse was supported on six legs. Six support legs were used to support the structure to avoid adverse effects associated with differential settlement and provided redundancy. The lower support structure was comprised of built up tubular sections adequately braced to ensure all loads were transferred to the foundation. Built up fabricated tubular steel members were utilized to provide significant resistance to lateral torsional buckling, due to the long laterally unsupported lengths. The physical size of these members was minimized to reduce the wind loading impact and corrosion exposure. Also with the ore processing mill in close proximity, emitting exhaust that causes steel corrosion over the long term corrosion exposure was a great concern. To counter this condition, continuous seal welding and an advanced coating system was specified to keep the hollow sections adequately protected especially with connection details. Since the lower steel was subjected to the hostile temperatures of the Canadian climate, the steel specified was a weldable notch tough type meeting a Charpy V-Notch Test requirement of 27J at minus 20°C.

The penthouse walls were designed to be a series of built up truss systems, maximizing support while minimizing the weight of the structure. Because the truss was stick built at elevation, the contractor needed to use cranes to support the midspan while installing the final member to complete the top cord. This system was preferred over cambering the bottom cord to allow the contractor to assemble at ground level and raised into position to minimize the number of large cranes on the confined site. The penthouse floor steel framing and decking was installed as the contractor ascended to the upper levels to allow for easier and safer access to the next level of construction (see figure 7). The concrete floors and hoist beams were constructed at this time for several reasons: easy, safe access to the floors with the concrete pump lines, to provide mass and lateral support for the structure. The concrete mass acted like a ballast stabilizing the tall structure during windy days amid construction and thus reducing the critical uplift values. The additional benefit of pouring the concrete floors was to provide safe access to the upper levels of the penthouse for the remainder of the construction. The deflection sheave was installed prior to pouring the floors above to facilitate schedule. Once the floors were poured and adequately cured, the remaining structural steel framework was completed, with the only exception being an opening in one end to the structure to allow for the 56 tonne overhead bridge crane to be installed. After the crane was installed and the remaining steel framing completed, the roof and cladding were installed. With the penthouse enclosed, the structure was ready for installation of the hoisting plant and supporting infrastructure.
To provide power for construction and equipment, two 15 kV power feeds and fibre optic cables were routed up one of the main legs using cable tray. One of the 15 kV feeds was allocated to power the hoist and the other was used for construction and equipment power; the power was stepped down using one of the underground transformer sleds. To outfit the headframe, the 56 tonne overhead crane, equipped with two high speed 5 tonne hoists, was used to raise the materials and equipment to the appropriate levels. The 10,000 kW friction hoist components were raised with the 56 tonne crane hoist and staged on the hoist floor. The hoisting power plant and controls were also installed and connected to the 15 kV feed. Upon completion of the hoist installation and power connections, a preliminary pre-commissioning was carried out to ensure that all components were operating within the ‘no load’ parameters. Other permanent equipment was also installed including the traction wheel elevator machine and various maintenance jib cranes and monorails. The heating and ventilation (HVAC) equipment and ductwork was installed and powered using the temporary power supply. A temporary gas line was routed up the outside penthouse leg to provide the necessary gas supply for cold weather heating. Compressed air lines, fire protection piping, dry chemical units and the permanent roof drains were installed, and the temporary drain line was run down the penthouse tower leg and diverted to the water management plan.

All cable trays were installed throughout the penthouse as well as all welding plugs, receptacles and lighting. The penthouse was operational and ready for rope up and final permanent services connection after the new headframe was constructed.
HEADFRAME COMPLEX

The headframe complex is the structure below the hoisting plant penthouse and contains the shaft access, the dump system, material surge bins, material handling, conveyance arrester system and catch gear, as well as all services required to maintain and operate the production headframe facility. Adjacent to the headframe is a power and controls room, collar house, bin house, shop and a mine air exhaust ventilation system. The environment is controlled through heating and ventilation and the entire space is protected with a fire detection and protection system. The headframe construction/erection was divided into two stages, erection prior to service headframe demolition and erection after demolition.

Based on the early works plan where structures that could be constructed prior to the demolition of the existing structure, the MCC / power room and the operator’s room was designed to be a free standing system. Since the structure would stand alone for a period of time, the foundation system and the structural support had to be designed to incorporate this independent support condition whilst avoiding future operation interference or encumbrances. After the structure was constructed it was outfitted with all hoisting control consoles, power and controls equipment, HVAC system, plumbing and lighting. The next stage of the project was the removal of the existing service headframe.

To decommission the old service headframe a systematic plan to safely remove the structure was developed. The first course of action was to derope and remove of all equipment from the headframe. Next was the removal of the structural penthouse and to assist with this plan, a finite element analysis model of the existing service headframe was developed and updated as the members were removed to ensure structural integrity was maintained. This approach was executed until the entire structure was removed. Now that the headframe was removed, the new modular headframe was ready for assembly.

The main headframe tower was designed to be handled and moved as modular units (see figure 8). These modules were constructed in a fabrication shop and shipped to site as large units where they were staged on a track system until required to be moved into place for installation. While in this staging area, the modules were outfitted with fire protection systems, fire pump, gas lines, unit heaters, air handling units, ductwork, plumbing, cable tray and power and control cables. The first modules that were installed were the stair tower. These modules were designed to be self-supporting with temporary cross bracing, and requiring minimal lateral support. Each unit was moved into the appropriate lifting position on a track system via construction rollers and raised into place using cranes with a spreader frame rigging with the last section of the stair tower stick built in place. Once the stair tower was installed, the main headframe tower modules were moved into place using the same track system, but this time the modules were raised using a strand jack system installed in the penthouse on the deflection sheave floor. These modules were physically connected to the penthouse with a temporary, but substantial connection and these were installed from the top down. The stair tower offered lateral support and access to the modules. The lower part of the headframe and collar houses were stick built. The columns had jacking supports to allow the entire tower to be raised up to remove load from the penthouse connection, and allowed the termination of the penthouse connection. The tower was plumbed and lowered into the appropriate position, and then shimmed and connected to the concrete piers. Although there is no vertical connection between the penthouse and the headframe, the penthouse provided lateral support to the lower headframe in the final configuration. Once the headframe tower was constructed, the lower bin support was erected and the modular bins were assembled on the supports. After the structure was erected, the ductwork, piping and electrical connections between the modules and between the penthouse and the headframe were completed.
DISCUSSION

Early Works Planning

The critical path for this project was the headframe erection time after the demolition of the service headframe. This required extensive planning to schedule as much work to be completed prior to service headframe demolition. The plan to design for and execute this work was known as the early works program. Though designing main headframe to be modular was the primary element of the early works program, there were several other items that qualified:

- Construction of foundations outside the service headframe
- Rerouting the shaft power and signal cables
- Construction of the operators / power room
- Pouring the west collar house floor

Operational Considerations

Since the original function of the shaft was for service, the diameter was not ideal for conveyances of this size so some creativity was required to layout the conveyance support elements. The shaft conveyance clearances of 450 mm governed the location of
conveyances in the headframe and the horizontal clearances to accept the catch gear, arrestors and fixed guides. With the wide side of the conveyance being used to dump, to maintain the largest possible dump opening, the narrow side was available for placement of the guide system, arresting system, and catch gear. The conveyance was guided in the shaft by rope guides and in the headframe / shaft bottom by fixed guides as is conventionally done. Due to the reduced space available, the fixed guides in the headframe occupied the same space as the rope guides, this was made possible by integrating the rigid rope guide slipper and the fixed guide slipper as one element, (see figure 9). The conveyance slipper was designed to be more robust than conventional rope guide slippers, in order to not only guide the conveyance on the guide ropes in the shaft, but also to guide the conveyance in the headframe and shaft bottom through the dump zone and arrestors to crash. Since the conveyance guide had 2 running surface faces, the fixed guide system in the headframe needed to be a pocket to contain the conveyance throughout the dump and arrestor zone. This was achieved by designing a built up structural member with wear plates along the running surfaces. The rigid guide cradle and the arrestor columns were located very close to each other, so all column connections were slotted to allow 50 mm of adjustment in any direction. The arresting crosshead was specially designed to operate in this confined space and was provided with clearance to the skip yoke, required to activate the dump door on the Sala skip and providing clearance during an overwind event without damaging the skip yoke umbilical cord.

<Figure 9. Conveyance arrangement>

CONCLUSION

The decision to convert an existing service shaft to a production shaft was made based on logistics, cost and schedule. Though there were many considerations that influenced the design and construction throughout the project including operational compliance, constructability, functionality, client preference, corrosion resistance, durability, aesthetics and cost; the most influential factor to warrant this approach was the project schedule. Any areas where the schedule could be expedited in a safe manner were thoroughly evaluated. The design employed to complete this project as described in this paper allowed for an expedited schedule, making the project a success.

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