Impact of Geotechnical and Hydrogeological Parameters upon Shaft Sinking Performance in the Athabasca Basin Canada

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Abstract
Shaft sinking in the Athabasca basin, Saskatchewan, Canada requires sinking through water bearing sandstone. Intersection of local zones of extensive fracturing results in the potential for high water inflows, which makes shaft sinking very challenging. This paper compares pre-shaft sinking data collected in the Athabasca Basin from shaft pilot holes with actual experience observed during shaft sinking. An attempt was made to correlate the observations from grouting of local fracture zones exposed by shaft excavation under high hydrostatic pressure head and flow to the geotechnical and hydrogeological parameters determined from the pilot boreholes This study is expected to predict anticipated shaft sinking conditions for the new Millennium Mine of Cameco Corporation in Athabasca Basin where two shaft pilot holes were drilled recently.

Key words: McArthur River mine, Cigar Lake mine, Athabasca Basin, uranium, shaft sinking, bulk hydraulic conductivity

Introduction

This paper presents the comparison of pre-shaft sinking data collected in the Athabasca Basin of Saskatchewan, Canada from shaft pilot holes to the actual shaft sinking experience observed in the field. Shaft sinking in Athabasca Basin has met with varying degrees of success almost entirely due to the magnitude of groundwater and flowing sand conditions encountered. Data from three shafts at McArthur River Mine and one at Cigar Lake Mine is used in order to identify correlations that will impact the decision making process for future shafts. Both mines are located in northern Saskatchewan and are operated by Cameco Corporation, the largest single producer of uranium in the world. This comparison is expected to provide insight into anticipated shaft sinking conditions at Cameco Corporation's new Millennium mine in the Athabasca Basin where two shaft pilot holes have been completed recently.

Shaft sinking geology and its relation to past experience

The McArthur River mine and Cigar Lake mine are located in the southeastern part of the Athabasca Basin in northern Saskatchewan, Canada. The Basin occupies an area of about 100,000 sq km in northern Saskatchewan and straddles the Alberta-Saskatchewan border. It is considered to be one of the most favourable places in the world for exploring and mining uranium and accounts for approximately 30% of global primary uranium production. The high-grade unconformity-type uranium deposits within the Athabasca Basin are associated with the unconformity between the essentially flat-lying Proterozoic Athabasca Group sandstones and the underlying Archean-Paleoproterozoic metamorphic and igneous basement rocks of the Rae and Hearne Provinces. Three distinct geological units traversed during shaft sinking in Athabasca basin are surface overburden, sandstone, and basement rock. Overburden in all sites selected to date for shaft sinking comprises of sandy soils with silt layers and boulders. The use of a box cut over ground freezing has been preferred in the past for the sinking depth to be completed in overburden primarily due to significant cost savings in terms of time. Ground water elevation in the overburden has proven to be a modest but not overriding factor for the shaft location criteria.

Shaft sinking performance and cost is most influenced by hydrogeological and geotechnical parameters of the Athabasca sandstone. The sandstone is water bearing and requires grouting to reduce the ultimate inflow rate into the finished shaft. The sandstone has been broadly classified into four units in the McArthur River and Cigar Lake mine area. Additional technical information on the differences between the four units can be found elsewhere, see for e.g. Yeo et al. 2002 .The near surface MFd unit has not caused sinking or grouting concerns in the past but this may be due to the low static groundwater pressure. The MFc unit encountered in the past shaft sinking experience has

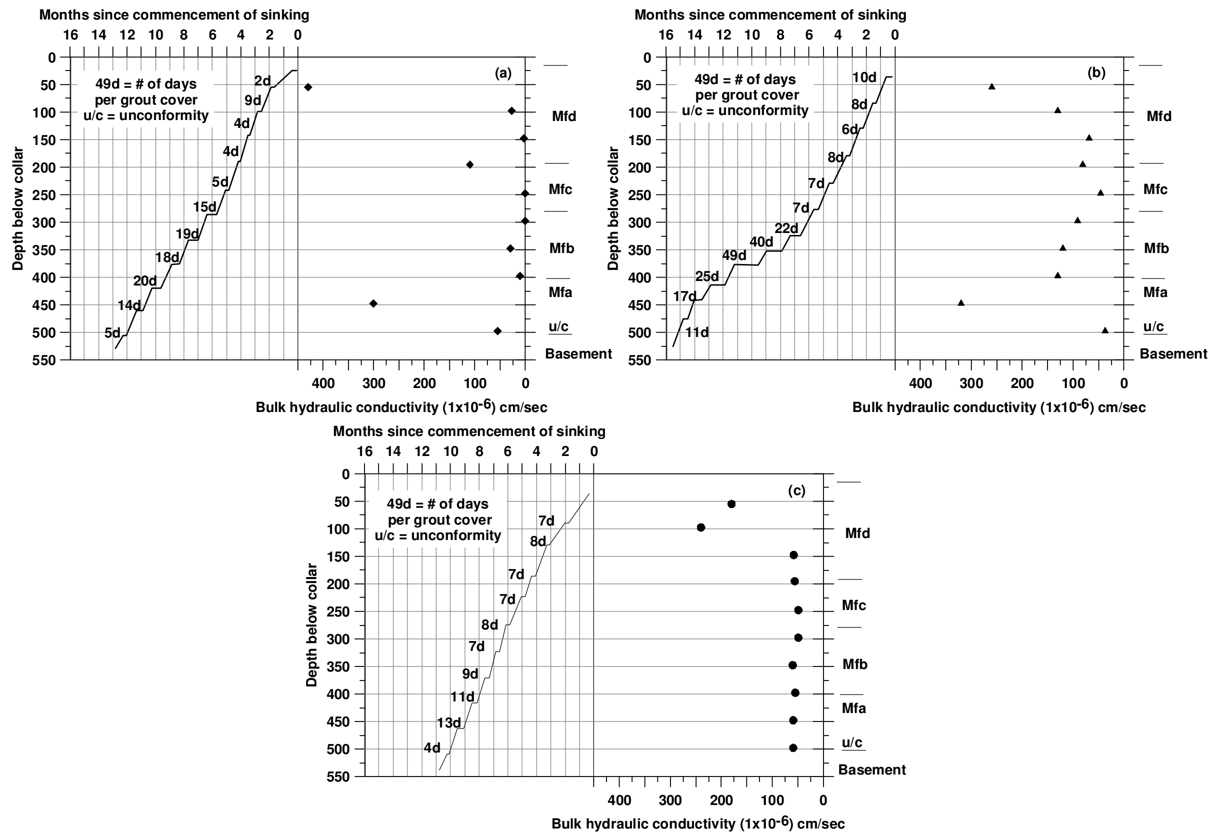
been fine grained with wide joint spacing; with low groundwater flow rates. The unit is least likely to provide grouting difficulties in future shaft sinking endeavors. Past shaft sinking experience has indicated that the MFb unit has been the most problematic to grout due to higher than average inflow rates encountered in grout holes and the occasional intersection of unconsolidated sand. The MFb unit at McArthur River appeared to be coarser grained than the MFc unit and, on occasion, the coarser grained pebbles do not appear to be totally cemented in the sandstone matrix. The MFa unit at McArthur River has been impacted by local silicification so it is difficult to comment upon the potential grouting characteristics if unsilicified at future shaft sinking sites. There is anecdotal evidence that the water bearing fractures are finer due to this silicification (greater use of ultrafine grouts necessary). This unit proved difficult to grout at times in the #1 and #2 Shafts at McArthur River. The MFa unit is absent at Cigar Lake Mine area.
Basement rock generally consists of gneissic, granitic or pelitic type rocks, which are massive in nature. In general, basement rock has not presented many technical challenges during shaft sinking but can require standard ground support bolting due to the orientation of joints, fractures and schistocity planes. Paleoweathering alteration may be present near the unconformity, which could increase support needs. Fresh high strength (>100 MPa) basement rock is encountered at McArthur River 20-30 metres below the unconformity but at Cigar Lake, evidence suggests that the basement rocks do not obtain this strength or general competency. Minor water flows (< 2 m^3/hr) may be encountered in the basement rock generally within 10 meters of sandstone. The source of this water is presumably the sandstone.

Pre shaft sinking data collection
In order to obtain information in support of engineering design for shaft sinking, field investigations including, bore hole drilling, core sampling and logging, hydrogeological testing and groundwater sampling is usually carried out. The key objective of the hydrogeological investigations is to identify the potential zones of high groundwater inflows, which would have significant impact on shaft sinking methodologies and costs. The major component of the hydrogeological investigations is downhole packer testing to determine the bulk horizontal hydraulic conductivity over a given shaft interval. In addition to hydrogeological investigations, information on rock quality, typically done by assessing the rock mass rating or core RQD is the second source of data relied upon to provide an indication of shaft sinking performance. Core recovery from the bore holes at various depths is also taken into consideration, as it might be indicative of higher local hydraulic conductivity or presence of open ground which could act as a groundwater conduit. Additional geotechnical testing such as ·caliper testing, computed density, apparent porosity, sonic wave testing, sonic wave testing and compressive strength testing of the pilot holes in the past have not provided material benefits to improve the shaft sinking efficiency.

Shaft sinking performance at McArthur River Mine
Relative shaft sinking performance for the three shafts is illustrated in Fig. 1 together with hydraulic conductivity data collected in shaft pilot holes. From this figure it can be observed it took three more months to sink #2 Shaft compared to #1 Shaft and five more months compared to #3 Shaft. Since the shaft-sinking rate per day is similar for all three shafts, it is clearly evident that the reason for poor performance in #2 Shaft was due to difficult and extended grout covers The hydraulic conductivity values measured in the shaft pilot holes for all three shafts indicate high values in first 100 m of depth, however, extensive grout covers were not required due to low hydrostatic conditions at relatively shallow depths. From the hydraulic conductivity profile with depth it can be observed that for shaft # 3 pilot hole the lowest permeability at depth was observed with little variation in the values with depth. This observation correlates well with the fact that the #3 Shaft at McArthur River proved to be the least problematic of all shafts sunk to date and thus signifies the impact of hydraulic conductivity on shaft sinking performance. The poor performance of #2 Shaft in terms of time required were related to the grouting difficulties, which can be correlated with higher permeability readings from the shaft pilot hole. However it should be noted that the grout covers #8 and 9 in #2 Shaft were particularly difficult as on three occasions during cover #8, grout holes encountered flows of 75-100 m^3/hr with one strong flow accompanied by sand. This is in contrast to grout covers #10 and #11, which were also in higher permeability areas with flows up to 50 m^3/hr but with an absence of sand in the flows. The absence of

sand at these locations can be due to increased silicification of sandstone with depth observed at McArthur River and is indicative of the increased local rock strength. The lack of free flowing sand in fractures lead to less complicated grouting but extended grout times were still necessary although less than those required for #8 and #9 covers. Therefore it can be concluded that the higher hydraulic conductivity values alone are not the only indication of anticipated shaft sinking conditions and more effort should be spent on detecting the presence of unconsolidated sand layers with depth.

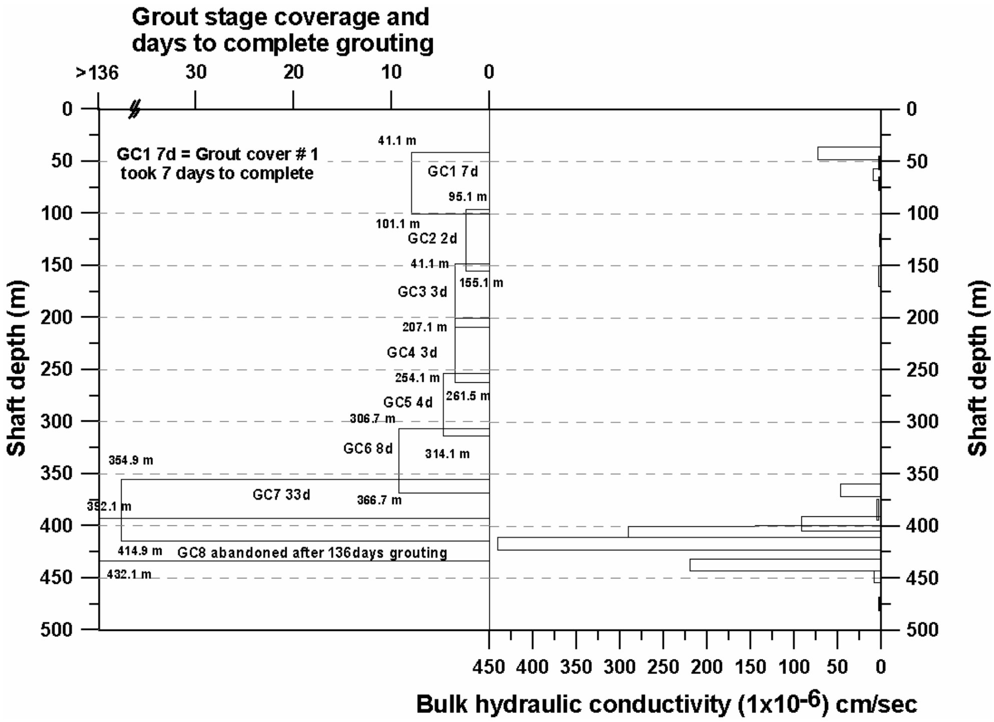
Figure 1 *Relative shaft sinking performance at McArthur River (a) # 1 shaft, (b) #2 shaft, (c) #3 shaft*



Shaft sinking performance at Cigar Lake #2 Shaft

Despite the different packer interval used for Cigar Lake pilot hole testing there are a number of similarities when comparing sinking performance for McArhtur River Mine and Cigar Lake Mine. Figure 2 illustrates shaft-grouting performance versus bulk hydraulic conductivity for Cigar Lake Shaft # 2. It is clearly evident that there were few grouting difficulties in the first six grout covers where hydraulic conductivity was generally lower than McArthur River #3 Shaft. However, the hydraulic conductivity below 400 m depth appears to be the reason for complications with grout covers #7 and #8 .Only one of 16 initial grout holes in grout cover #8 intersected a sand filled structure that ultimately produced in the order of 1,000 tonnes of sand into the shaft bottom for removal by sinking bucket. The ultimate quantity of sand in this area is unknown. Over four months were spent attempting to flush and grout this sand bearing structure prior to conceding that ground freezing methods would be required to consolidate this area to allow shaft advance. Shortly after this change in plan the shaft flooded due to an unsecured grout hole gate valve. It is difficult to state with certainty that the higher conductivity observed in this area was in any way related to the sand structure encountered. However, as discussed previously, similar, though manageable difficulties were encountered at McArthur River #2 Shaft in areas at depth with similar conductivities. The recommendation therefore is to avoid locating shafts in such areas. Although this recommendation may lead to “false positives” and the need for additional pilot holes, this is a far better outcome than significant shaft delays with total costs of up to $50,000 per day, or worse yet, a $50-75M shaft that cannot be completed as planned for technical reasons. This also emphasizes the need for further data collection such as the seismic surveying program recently completed at the Millennium project.

Figure 2 *Grouting performance vs. bulk hydraulic conductivity Cigar Lake # 2 Shaft*



Conclusions and Recommendations

1. The grouting performance impacts the overall project performance and the bulk hydraulic conductivity from the pilot shaft holes can be correlated to the grouting performance.
2. The #3 Shaft at McArthur River proved to be the least problematic of all shafts sunk to date. This performance correlated to the lowest conductivity at depth with little variation with depth. Hydraulic conductivity data from the shaft # 3 pilot hole can be used as the benchmark for future shaft site selection.;
3. The presence of sand in or near the shaft perimeter can detrimentally impact the sinking performance and in extreme cases lead to the need to abandon cement grouting techniques in favor of ground freezing;
4. Methods to detect the presence of sand structures prior to accepting a pilot hole as a suitable shaft location is highly recommended. One such method is downhole seismic surveying.
5. Higher permeability near surface has not proven challenging due to low static groundwater pressures.

References

Yeo, G., Jefferson, C.W., and Ramaekers, P. (2002): A preliminary comparison of Manitou Falls Formation stratigraphy in four Athabasca Basin deposystems; in Summary of Investigations 2002, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2002-4.2 CD-ROM, Paper D-7, 14p.