Mine Water Environ (2014) 33:289–292
DOI 10.1007/s10230-014-0261-0

TECHNICAL COMMUNICATION

Grouted-in Pressure Transducers: Implications for Hydrogeological Testing and Monitoring in Bedrock

Willy Zawadzki · Don Chorley

Received: 16 July 2013 / Accepted: 5 February 2014 / Published online: 16 February 2014

Abstract Grouted-in pressure transducers are commonly deployed at open pit and underground mines to monitor hydraulic heads in bedrock near the mine working and to provide information on the progress of dewatering/depressurization efforts. Grout mixtures typically have a lower hydraulic conductivity than permeable features that act as conduits for groundwater flow in bedrock. Therefore, a question often arises as to how grout properties affect measurements of hydraulic head when compared to installations with pressure transducers embedded in sand pack or installed in conventional standpipe piezometers. A series of numerical simulations have been completed to illustrate the hypothetical response of a grouted-in pressure transducers and the response of an "ideal" instrument that is not affected by grout properties. For the range of parameters tested, these simulations indicated that the grouted-in transducers resulted in a "lag" in pressure response of a few hours following initiation of the hydraulic stress compared to the response of the sand packed transducer. Thus, care needs to be exercised when estimating hydrogeological properties from tests that rely on a network of grouted-in transducers. The numerical simulations also suggested that approximately 1 day after the initiation of hydraulic stress, the readings recorded by a grouted-in transducer were essentially the same as readings that would be obtained from an "ideal" instrument. Longer-term monitoring of hydraulic heads behind the pit walls using such instruments thus appears to be a viable alternative at mine sites.

W. Zawadzki (✉) · D. Chorley
Golder Associates Ltd, 500-4250 Still Creek Dr, Burnaby, BC V5C 6C6, Canada
e-mail: wzawadzki@golder.com

Keywords Mine dewatering · Depressurization · Monitoring · Piezometers · FEFLOW

Introduction

Hydrogeological testing and monitoring at mining sites is required to understand and mitigate adverse effects resulting from large inflows and high groundwater pressures in the vicinity of mine workings. A well designed instrumentation network will help assess whether dewatering/depressurization targets are met, and in locating future areas of potential higher inflows where additional dewatering measures should be deployed. This network can also be used for interference testing (e.g. pumping tests) to characterize hydraulic conductivity (K) of the rock mass near the mine, a critical parameter for mine inflow predictions. Monitoring of hydraulic heads relies broadly on two types of instruments: (1) standpipe piezometers where hydraulic head is measured in a steel or plastic casing that is screened (perforated) within the interval where head monitoring is required, and (2) piezometers that relay on pressure transducers (pneumatic or vibrating wire) that are installed in boreholes and provide a hydraulic head measurement at a point below the ground surface.

Two general methods are available for the installation of downhole pressure transducers. The first method, as discussed by Contreras et al. (2008) involves grouting-in the entire borehole after the transducer(s) is lowered to the desired depth. In this installation method, the transducer tip is fully surrounded by the grout material. In the second method, the borehole above and below the transducer is grouted; however, the transducer tip is embedded in a sand pack of sufficient length to prevent grout from coming in contact with the transducer tip. As discussed by Mikkelsen

(2002), Mikkelsen and Green (2003), and Simeoni et al. (2011), the second method is quite labor intensive and time consuming, and often results in poor placement of the sand pack. Nevertheless, because the sand pack K is typically higher than the K of surrounding rock mass, pressure transients are transmitted across the sand pack to the transducer tip without any delay.

Grouted-in pressure transducers are common at mine sites, in part due to the ease with which several transducers can be installed in a single borehole. Such installations, when deployed in an array of strategically placed boreholes, allow for high-resolution monitoring of hydraulic head changes as mining advances. As demonstrated previously by Contreras et al. (2008) for conditions where hydraulic heads have equilibrated and are at steady state conditions, the errors that grouted-in transducers introduce in the reading of hydraulic heads are essentially negligible when the K contrast between the grout material and the surrounding sediments is less than approximately a factor of 1,000. This suggests that, for the typical range of grout K, negligible errors in head measurements would be introduced by grouted-in transducers in most bedrock settings when groundwater conditions are close to static. However, the effect of short-term changes in hydraulic heads that typically occur during hydrogeological testing or activation/deactivation of depressurization systems (e.g. well fields, drainage galleries) on readings obtained from grouted-in transducers is not well understood, and is the topic of this technical note.

Methods

The performance of a grouted-in transducer was evaluated using a numerical groundwater model constructed using FEFLOW (Diersch 2012) to represent a simplified scenario that considered a single pumping well and a single observation well. These installations were assumed to be completed in a permeable feature that represented a bedrock discontinuity with permeability enhanced relative to the surrounding rock mass. Model discretization was such that it allowed for representation of the grouted-in piezometer in the center of a 0.1 m diameter borehole (Fig. 1) and a measurement point immediately outside of the borehole/grout interface (i.e. the “ideal” instrument not affected by grout properties). A series of simulations were then completed using this simplified model to illustrate hypothetical response to a 1-day pumping test in the grouted-in transducers and the response in this “ideal” instrument. Predicted response was also compared to the Theis (1935) solution for pumping test interpretation as implemented in the AQTESOLV aquifer test analysis software (Duffield 2007).

The hydrogeological parameters assigned to the permeable feature and grout material were selected to capture typical conditions encountered at mine sites. Hydraulic conductivity of the permeable feature (K_f) was assumed to range between 1×10^{-6} and 1×10^{-5} m/s, which encompasses the testing results in features discussed by Bieber et al. (2006, 2007) at the Diavik Mine in the granitic bedrock of the Canadian Shield. Grout hydraulic

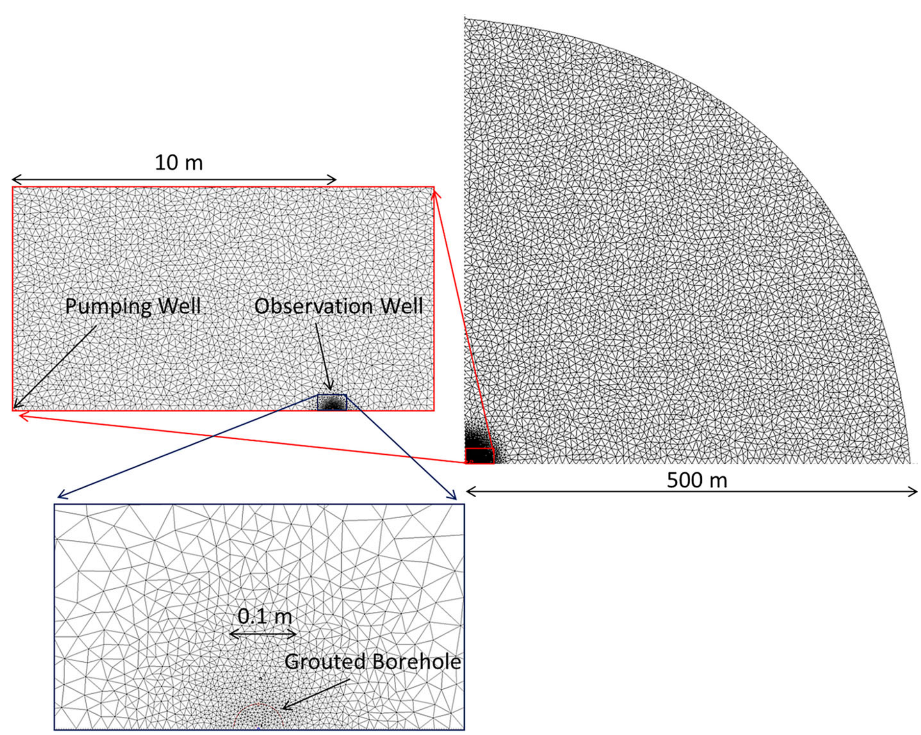

Fig. 1 FEFLOW numerical model representing a simplified scenario with a single pumping well and an observation well completed in a permeable feature

conductivity (K_g) was varied between 1×10^{-11} and 1×10^{-7} m/s, based on values reported by Mikkelsen and Green (2003), Contreras et al. (2008), and Simeoni et al. (2011) for various water-cement-bentonite mixtures. Specific storage of 1×10^{-5} and 1×10^{-4} 1/m was assigned to the permeable feature and the grout material, respectively, based on typical values provided in Maidment (1992) and Mikkelsen and Green (2003).

Results and Discussion

Figure 2 presents the error between the drawdown predicted for a grouted-in transducer and the "ideal" instrument, expressed as a percentage of the ideal response, for all combinations of permeable feature and grout properties considered in the model. For a permeable feature with K of 1×10^{-5} m/s, this error was about 20 % initially and essentially negligible after 0.001 day of pumping for a K contrast between the grout material and the surrounding sediments of 100; it was 100 % initially (i.e. drawdown at the grouted-in transducer was essentially nil) but decreased to less than 2 % after 0.01 day of pumping for a K contrast of 10,000; and was initially 100 % but decreased to approximately 1 % at the end of a 1 day long pumping period for a K contrast of 1,000,000. When a permeable feature with a K of 1×10^{-6} m/s was considered, overall results were similar but the times for the errors between the grouted-in transducer and the "ideal" instrument to diminish increased slightly due to slower propagation of the drawdown cone in the lower K permeable feature. For a conductivity contrast of 1,000 in this scenario, the predicted drawdown in the grouted-in transducer became essentially identical to the ideal drawdown after approximately 0.1 day, supporting earlier work completed by Contreras et al. (2008).

The results (Fig. 2) suggest that, for most combinations of parameters tested, the drawdown predicted for the grouted-in transducer is representative of drawdown in the permeable feature a few hours after the initiation of pumping. Thus, for monitoring of hydrogeological stresses that occur on longer time scales (days or months), data collected by these instruments should provide adequate representation of actual field conditions. However, for the short-term monitoring that is commonly employed for K testing, using data from grouted-in transducers could introduce errors in the test interpretation because pressure readings from these installations lag behind the actual response when the contrast between the grout and formation K exceeds a factor of ≈10,000. Figure 3 compares the drawdown predicted for all model scenarios considered in this technical note with the drawdown calculated using the Theis (1935) solution for a constant-rate test in a confined homogeneous aquifer. For conductivity ratios of less than 10,000 (Fig. 3 a, d, e), the predicted drawdown and its derivative are essentially identical to the theoretical drawdown, whereas for higher ratios (Fig. 3 b, c, f) the predicted and theoretical drawdown lags at early times, with this difference diminishing later in the test. This artificially steepens the drawdown versus time curve, when plotted on a semi-log graph, which could lead to erroneously low estimates of the hydraulic conductivity of the tested feature. For example, if the Theis theoretical curve is fitted to the portion of the predicted drawdown curve affected by this lag (Fig. 3c, K contrast of 1,000,000), the estimated hydraulic conductivity would be approximately five times less than the actual value. Thus, care needs to be exercised when designing monitoring networks for interpretation of short-term hydraulic responses by using grout mixtures with a K that is not too low relative to the features tested, and by careful analysis that recognizes the potential effects caused by using a lower K grout.

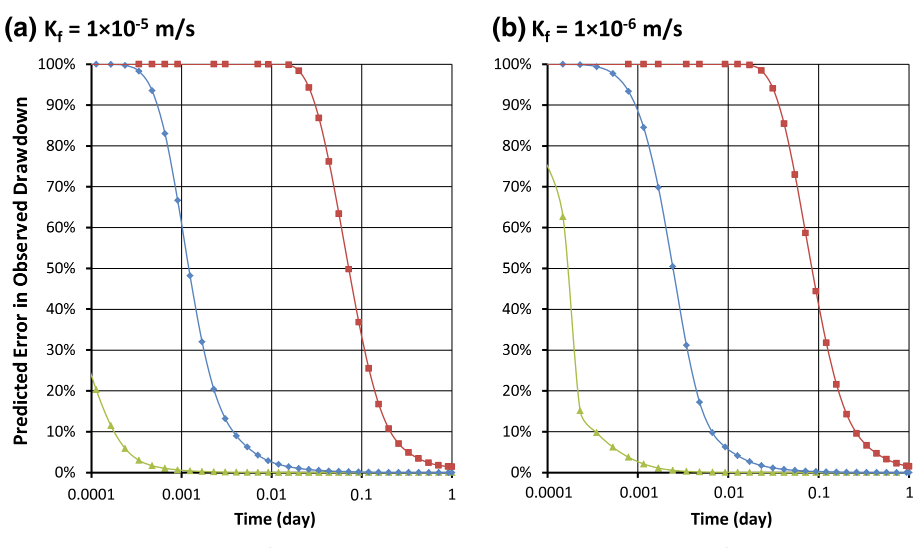

Fig. 2 Comparison of error between predicted drawdown at the grouted-in pressure transducer and the "ideal" instrument: **a** $K_f = 1 \times 10^{-5}$ m/s and pumping rate of 20 m^3/day; **b** $K_f = 1 \times 10^{-6}$ m/s and pumping rate of 4 m^3/day

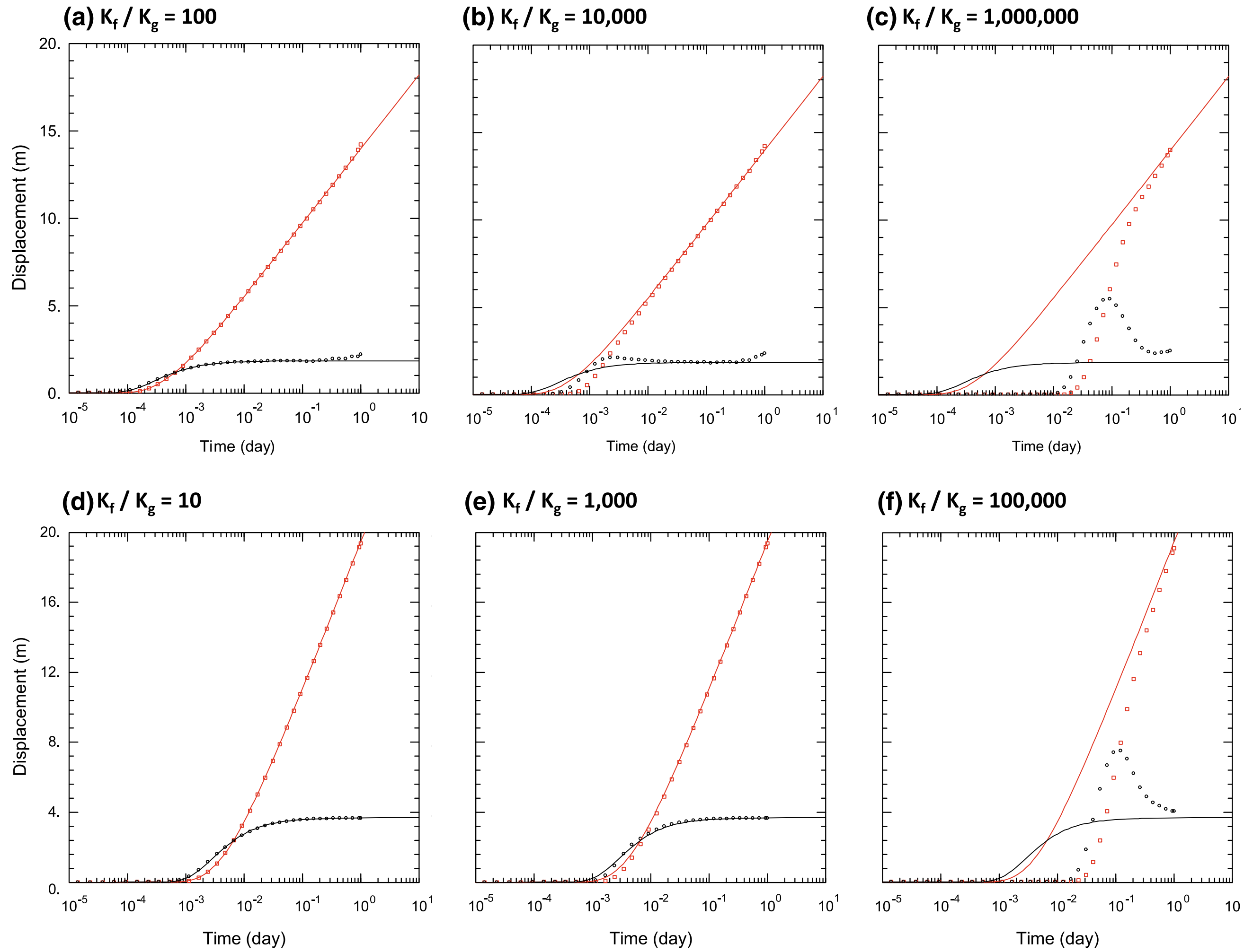

Fig. 3 Comparison of drawdown predicted at the grouted-in transducer with Theis (1940) theoretical drawdown: **a** $K_f = 1 \times 10^{-5}$ m/s, $K_g = 1 \times 10^{-7}$ m/s; **b** $K_f = 1 \times 10^{-5}$ m/s, $K_g = 1 \times 10^{-9}$ m/s; **c** $K_f = 1 \times 10^{-5}$ m/s, $K_g = 1 \times 10^{-11}$ m/s; **d** $K_f = 1 \times 10^{-6}$ m/s, $K_g = 1 \times 10^{-7}$ m/s; **e** $K_f = 1 \times 10^{-6}$ m/s, $K_g = 1 \times 10^{-9}$ m/s; **f** $K_f = 1 \times 10^{-6}$ m/s, $K_g = 1 \times 10^{-11}$ m/s; *symbols* represent drawdown (*red*) and drawdown derivative (*black*) predicted using the FEFLOW model; *lines* represent drawdown (*red*) and drawdown derivative (*black*) calculated using Theis (1935) solution

References

Bieber C, Chorley DW, Zawadzki W, Reinson JR (2006) Hydrogeologic data collection and development of conceptual models to predict mine inflow quantity and quality at Diavik Diamond Mine, NWT. In: Proceedings of 59th Canadian geotechnical conference and 7th Joint CGS/IAH groundwater specialty conference, Vancouver, BC, Canada

Bieber C, Moffitt K, Chorley DW, Zawadzki W, Greer S (2007) Detailed evaluation of pit slope stability in fractured rock and kimberlite slope—Diavik Diamond Mine, NWT. In: Proceedings of 60th Canadian geotechnical conference and 8th Joint CGS/IAH groundwater conference, Ottawa, ON, Canada

Contreras IA, Grosser AT, VerStrate RH (2008) The use of the fully-grouted method for piezometer installation. Geotech News 26(2):30–40

Diersch HG (2012) FEFLOW v. 6 finite element subsurface flow and transport simulation system. DHI-WASY Institute for Water Resources Planning and System Research Ltd, Berlin

Duffield GM (2007) AQTESOLV for Windows v. 4.5, user's guide. HydroSolve Inc, Reston

Maidment DR (1992) Handbook of Hydrology. McGraw-Hill, NYC

Mikkelsen PE (2002) Cement-bentonite grout backfill for borehole instruments. Geotech News 20(4):38–42

Mikkelsen PE, Green GE (2003) Piezometers in fully grouted boreholes. In: Proceedings of 6th international symposium on field measurements in geomechanics. Oslo, Norway, 15–18 Sept 2003

Simeoni L, De Polo F, Caloni G, Pezzetti G (2011) Field performance of fully grouted piezometers. http://www.sisgeo.com/wp-content/uploads/2011/09/Fully_Grouted_Piezometer_Paper-SIMEONI-DEPOLO-CALONI-PEZZETTI.pdf. Accessed 10 July 2013

Theis CV (1935) The relation between the lowering of the piezometric surface and rate and duration of discharge of a well using groundwater storage. T Am Geophys Union 2:519–524