Hydrogeological Assessment of the Thar Lignite Prospect

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Abstract The paper is concerned with the hydrogeological appraisal of the proposed mining operations in the Thar Lignite field in Sindh, Pakistan containing lignite reserves >9 billion tonnes. The presence of three main aquifers surrounding three lignite seams induces pore pressure in the rock mass making the high wall slopes potentially unsafe. In order to dewater the surrounding rock mass before commencing mining excavations groundwater inflow predictions were carried out using a SEEP/W finite element software package. The simulation results for the three aquifers are presented indicating that the relative error of estimation between analytical and the numerical solutions vary from 3.4 % to 6.4%.

Key Words open cut mining, hydrogeology, aquifers, thar lignite mine, advanced dewatering,pumping out tests, mine water inflow

Introduction

The Thar lignite/coal field situated in the Eastern part of Sindh province in Pakistan is considered to be the seventh largest lignite deposit in the world containing some 193 billion tonnes of lignite resources. This paper is concerned with the hydrogeological appraisal of the proposed mining operations in this lignite field. A finite element SEEP/W computer software package has been used to calculate dewatering quantities from three aquifers associated with the lignite seams under consideration; one unconfined aquifer and two confined aquifers; one under artesian conditions. This will facilitate the dewatering of rock mass surrounding the open cut mining excavation, thus ensuring excavation stability and the economic viability of the mining operations.

Thar lignite/coalfield

The Thar lignite/brown coalfield is located in the South Eastern part of Sindh province at a distance of some 400kms from the city of Karachi. The lignite field was first discovered in 1994, and since then feasibility studies have been separately carried out on in blocks I and II by RWE Power International, Germany, and a Shenhua exploration group from China (RWE Power International 2004).

Stratigraphic section and lithology of the Thar coalfield

A stratigraphic section and lithology of the Thar coalfield indicates that the lignite seams occur in the Bara formation belonging to the Palaeocene/Eocene age. The Bara formation consists of 90m of thick sandy/silty claystone and sandstone strata with depths varying from 125m to 200m. There are number of brown coal/lignite seams of varying thickness, ranging from 12 to 21m, at an average depth of 170m. Underlying the Bara formation is basement rock that is light to grey medium compacted granite comprising fine to coarse quartz grains. Above the Bara formation is the sub-recent formation comprising inter-bedded carbonaceous sandstone, siltstone and claystone up to 65m thick lying at a depth of 52—125m. Overlying the sub-recent formation is 50m of thick dune sand which is a recent formation comprising fine to medium grained yellow greyish sand containing Ferro-magnesium minerals.

Hydrogeology

There are three major aquifers in the Thar coalfield designated as Top aquifer, Intermediate aquifer and Bottom aquifer. The Top aquifer (TA) is located at the base of the dune sand and extends all over the Thar Desert. In the mining prospect, the Top aquifer has a water column up to 5m and the water table is 10 to 12m above the mean sea level. The permeability co-efficient of the top aquifer is $3 \cdot 10^{-7}$ m/s. The Intermediate aquifer (IA) comprises scattered lenses in sub-recent and Bara Formations with the permeability co-efficient varying from 10^{-5} to 10^{-7} m/s with water table 10—20m above mean sea level. The Bottom aquifer (BA), which is the most dominant aquifer in the Thar coal field in terms of thickness, lateral extension and permeability, is located at the base of the lignite seams and reaches down to the granite basement. The Bottom aquifer, in the vicinity of bore hole RE-25, is 50—60m thick and increases in thickness westwards. This aquifer is an artesian aquifer with the piezometric head 25m above mean sea level and therefore, it is necessary to depressurize the aquifer before the open pit excavation reaches a mining depth of 100m to avert the danger of floor rupture and collapse of high wall slope.

Mine dewatering arrangements, pumping tests, and evaluation of aquifer parameters

Pumping out tests were conducted in boreholes RE-51 and RE-52 in the Bottom aquifer at a constant pumping rate over a period of 24 hours. Bore holes were equipped with 'Grungfos SP 30' submersible pumps 150mm in diameter with a maximum pumping capacity of 13 litres/m and delivery head of 40m. Drawdown of the aquifer as a consequence of pumping out was monitored on the observation piezometers $_{RE12P}$ and $_{RE-22}$. The results of pumping out tests on RE-51 well and RE-52 well indicate that permeability coefficient $k_{RE-51}=5.88 \cdot 10^{-5}$ m/s and $k_{RE-52}=2.63 \cdot 10^{-4}$ m/s. Mine dewatering arrangements comprise of the following four main elements as shown in Fig. 1 and outlined as follows:

- Dewatering ditches to divert water from the surface hydrological cycle.
- First stage pumping out of wells to dewater unconfined aquifer
- Second stage pumping out of wells to depressurize intermediate aquifer
- Third stage pumping out of wells to depressurize the base aquifer.

Surface Dewatering Ditch

A review of the rainfall data from Mithi district indicates that a daily maximum precipitation of around 100mm /day is expected during the months of July and August. This will lead to some flooding of the lowest mine bench without hampering the mining operations on the upper benches. It is expected that during unexpected rainfall the entire operation of the mine may close for a period of two days. The peak flow to the surface drainage system can be calculated, using the rational formula, as follows (Pathan et al, 2006):

$$Q = 2.78\ K\ A\ I = 2.78 \times 463.77 \times 0.58 \times 100 = 7.5 \times 10^4\ L/s$$

Where, Q = Peak flow in litres/s; A= Catchment area in hectares= 463.77 hectare, K= run-off co-efficient in decimal=0.58; I= rainfall intensity in mm/h=100mm/h

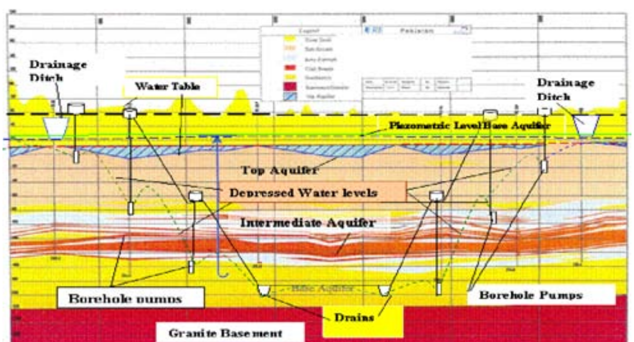


Figure 1 *Dewatering arrangements of three aquifers in Thar lignite Deposit (Pathan, et al. 2006)*

Table 1 Dewatering predictions of Thar Aquifers using equivalent well approach (based on Pathan et al. 2006)

Aquifer Characteristics	Pumping calculations
Top aquifer Aquifer thickness L= 5m;Drawdown D = 20m; Drawdown radius r = 1100m Radius of influence R = 1300m k=3 x 10-7 m/s= 0.0259 m/d T= 0.0259 x 5 = 0.13 m2/d;h= 12m, H=20m	**Unconfined steady state linear aquifer** Modified Dupuit (1863) Equation (Kruseman and De Ridder, 1979) $Q_{u} = \frac{\pi k (H^2 - h^2)}{\ln \{R/r\}}$ $= \frac{3.14 \times 0.0259 \times (20^2 - 12^2)}{\ln \{1300/1100\}} = 116 \; m^3/d$
Intermediate aquifer Scattered lenses K= 10-6 m/s= 0.086 m/d Drawdown required D = 80+20 = 100m Thickness of aquifer L= 10m Radius at drawdown r = 1050m Radius of influence R= 2500m; n=0.5	$Q_{u} = \frac{2 \pi k L D}{\ln \{R/r\} - n/2}$ Peterson Equation(Kruseman and De Ridder, 1979 $= \frac{2 \times \pi \times 0.86 \times 10 \times 100}{\ln \{2500/1050\} - 0.5/2} = 147 \; m^3/d$
Base Aquifers kRE-51=5.88 x 10-5m/s kRE-52=2.63x10-4 m/s Drawdown =205+55=260m Aquifer thickness L=55m Radius of draw down r=750m Radius of influence R= 2050m (assumed) n=0.5	$Q = \frac{2 \pi k L D}{\ln \{R/r\} - n/2}$ Peterson Equation (1954) (Kruseman and De Ridder, 1979) $Q_{RE-51} = \frac{2 \times 3.14 \times 5.88 \times 10^{-5} \times 55 \times 260}{\ln \{2050/750\} - 0.5/2}$ $= 0.699 \times 10^{6} \; m^3/d$ $Q_{RE-52} = \frac{2 \times 3.14 \times 2.63 \times 10^{-4} \times 55 \times 260}{\ln \{2050/750\} - 0.5/2}$ $= 8.64 \times 10^{6} \; m^3/d$

Prediction of aquifers pumping rates

Pumping rates from the three aquifers at the Thar prospect have been calculated using the equivalent well approach by the Pathan et al 2006 as summarized in Table 1

Table 1 indicates that the permeability coefficients of the base aquifer as calculated by pumping out tests on boreholes RE-51 and RE-52 differ considerably presenting a large difference in predicted inflow quantities at the different part of the pit

Inflow prediction into fully penetrating pit using steady state flow condition

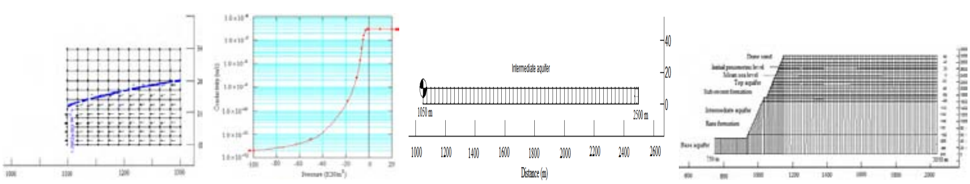
The following three different FE simulations were carried out to predict inflow by the Top, unconfined aquifer, intermediate confined aquifer and the Bottom Aquifer in a fully penetrating pit under steady state flow regime.

Unconfined Top Aquifer under steady state flow condition

The open pit in the unconfined aquifer was modelled as a fully penetrating pit with vertical walls with a constant head of 20m at the outer boundary of the model at a radial distance of 1300m. The radius of drawdown was 1100 m, a constant head of water was 12m at the pit, and permeability was $3.0 \cdot 10^{-7}$ m/s. Figure 2(a) shows the Finite Element model consisting of 132 nodes, 110 elements and 10 layers of 3m thickness each. Figure 2(b) shows the modified conductivity function assigned to the aquifer. The numerical results indicate that the inflow to the fully penetrating pit in top aquifer in steady state flow condition is 112 m^3/d.

Inflow from confined Intermediate aquifer under steady state flow condition

The FE model of the intermediate aquifer consisted of 55 elements, 116 nodes and a single layer 10m thick as shown in Figure 2(c). The input parameters to the model were: thickness of aquifer 10m, hydraulic conductivity $1.0 \cdot 10^{-6}$m/s, drawdown required 100m, the radius of drawdown 1050m and radius of influence 2500m. The numerical result predicted by the model was the inflow quantity of 141 m^3/d.



(a) (b) (c) (d)

Figure 2 Steady state flow analysis in a fully penetrating open pit in Thar lignite mine intersecting the Top, Intermediate and Bottom aquifers. (a) Finite Element grid, velocity vectors and water table of the Top unconfined aquifer, (b) Modifies hydraulic conductivity of the Top unconfined aquifer, (c) FE grid of Intermediate Aquifer, (d) FE grid of the Bottom confined aquifer.

Inflow from the Bottom confined aquifer under steady state flow condition

This simulation was performed to predict the ground water inflow from the Bottom aquifer to the fully penetrating pit to the Thar lignite mine under steady state flow condition as shown in Figure 2(d). The FE model comprised an axisymmetric grid consisting of 246 nodes, 120 rectangular elements in a single layer, 55m thick and 2050m long aquifer. The main input parameters assigned to the model were: thickness of aquifer 55m, hydraulic conductivity $2.19 \cdot 10^{-5}$m/s, drawdown required 260m, radius of drawdown 750m and radius of influence 2050m. The simulated inflow quantity to the fully penetrating pit was $1.28 \cdot 10^5$ m^3/d. If the Hydraulic conductivity was changed to $1.3 \cdot 10^{-4}$ m/s as calculated from the pumping well test on Well -RE52, the predicted inflow quantity to the pit was $1.4 \cdot 10^5$ m^3/d against $1.34 \cdot 10^5 m^3$/d calculated by the analytical method. Table 2 presents a comparison of analytical and numerical inflow results at Thar lignite mine for a fully penetrating pit into three aquifers under steady state flow conditions.

This simulation result indicates that 20 pumping-out wells equipped with 150mm diameter submersible motor pumps, type Grudfos SP30, will be required over a period of 10 years to achieve overall dewatering rate for top aquifer as 0.6 m^3/s. For Intermediate and Bottom confined or leaky aquifers high head borehole pumps with suitable ratings are needed.

Table 2 *Comparison of analytical and numerical mine Water Inflow in the Thar Lignite mine under steady state flow conditions*

Inflow Rate m^3/d	Analytical solution m^3/d	Numerical Solution m^3/d	% Error
Top unconfined aquifer	Q=116 m3/d	112	3.4%
Intermediate Confined Aquifer	Peterson Equation Q=147 m3/d	141	4.1%
Bottom Confined k=2.19x10-5m/s Aquifer k=1.3x10-4m/s	Peterson Equation Q=2.25x105 m3/d QAn=1.34 x 105m3/d	Q=2.34x105 m3/d Q=1.4x105 m3/d	6.4% 4.43%

Conclusions

This paper outlines a numerical axi-symmetric Finite Element model utilizing the SEEP/W software to predict inflow quantities from three aquifers including an infinite confined aquifer to the open pit in the Thar Lignite prospect located at 400km South East of city Karachi, Sindh, Pakistan. The model was then used to predict ground water inflow to the Thar lignite prospect into fully penetrating pit into the three aquifers using the steady state flow condition. It is concluded that the results of inflow can provide significant information for the design of an effective dewatering system for all stages of mining.

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