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UNCERTAINTY IN KARKHEH DAM FOUNDATION PERMEABILITY

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ABSTRACT

Karkheh Dam is the largest dam, in terms of reservoir capacity and volume of fill placed, constructed in Iran. Its foundation presents an unusual alternation of highly pervious conglomerate and layers of very low permeability mudstones. The pervious conglomerate is extremely inhomogeneous in nature with different matrix materials and different grade of cementation. At different stages of dam design, construction and impounding comprehensive study was performed to estimate the permeability of the conglomerate, which was a difficult engineering task. Due to complexity of the conglomerate formation, and the nature of procedures used, the estimated permeability values were significantly varied. Thus with data obtained from feasible methods of investigation and testing there remained significant uncertainty, especially in design stage. In this paper the results of these investigations are compared and discussions are made.

Keywords: Conglomerate, permeability, uncertainty, Karkheh dam, Lugeon test.

INTRODUCTION

Result of seepage analysis play a critical role in economic and technical investigations of a dam project. Permeability is the most important parameter for seepage analysis of a dam and its foundation; therefore, the prediction of permeability distribution for material of dam body and foundation is one of the critical aspects of dam projects. The permeability of the formation is usually evaluated from different methods such as Lugeon test, pumping test, etc. Normally all natural formations show some degree of heterogeneity due to the contrasting lithologies, digenesis, or sedimentological complexity. Characterization of heterogeneous formations is a complex problem since the sufficient data to accurately predict permeability is not usually available.

The foundation of Karkheh dam presents an unusual alternation of highly pervious conglomerate and layers of very low permeability mudstones. The pervious conglomerate is extremely inhomogeneous in nature with different matrix materials and different grade of cementation. Impervious mudstone layers interbed the conglomerates with 3 to 9 m in thickness, which are bedded near horizontal.

At design stages comprehensive study was performed to estimate the permeability of the conglomerate, which was a difficult engineering task. Different methods such as Lugeon and pumping tests were used in this investigation. Totally 823 Lugeon test at different layers at different locations were performed. Also pumping tests were carried out in two conglomerate aquifers below the riverbed. Using the data obtained from construction dewatering systems was another method used for permeability determination. Due to complexity of the conglomerate formation, the measured permeability varied in a broad range of about two orders of magnitude. Thus with data obtained from feasible methods of investigation and testing there remained significant uncertainty. Furthermore, the most part of the dam foundation was above the natural ground water level and therefore, reliable large scale hydogeological testing had not been possible.

Under this condition, an accurate and reliable prediction could not be taken. Instead, the decision had been taken to install a comprehensive monitoring system (Mirghasemi et al., 2000) and to slowly start reservoir filling. Remedial actions were taken as responses detected by the monitoring system (Mirghasemi et al., 2004). The investigation for conglomerate permeability estimation was continuously performed during construction and first reservoir filling. This paper reviews the procedure and results of permeability tests and seepage analysis carried out during the different stages of design, construction and first impounding.

1. KARKHEH DAM PROJECT

Karkheh Dam is the largest dam, in terms of reservoir capacity and volume of fill placed, constructed in Iran. It is a central core, zoned embankment dam 127m high, 3030 m long, with an embankment volume of 32 million cubic meters (Mahab Ghodss Consulting Engineers, 1998).

Karkheh River is the third largest river in Iran. The average annual discharge of the river is about 180 m^3/s. Karkheh Dam provides 3.6 billion cubic meters of water to irrigate 340,000 hectare of downstream farmlands. The irrigation of these farmlands is the principal goal of the project. Flood control and energy production of about 934 Giga watt hours are among other reasons for the dam construction. The reservoir is 60 km long and has a volume of 5.6 and 7.3 billion cubic meters at normal and maximum water level, respectively.

Figure 1. Karkheh storage dam, Andimeshk-Iran

A power house with total installed capacity of 400 MW is located at the left abutment (Figure 1). At the right side of the dam, the spillway with concrete chute of about 700 m in length and a 220 m long stilling basin is controlled by six radial gates. Karkheh dam foundation water tightness is achieved by means of a cutoff wall (Pakzad et al., 2001 & Shadravan et al., 2004). At the current situation, the wall surface area is about 190,000 m^2. The depth of the wall in deepest section is about 80 meters while the average of depth is about 50 meters. An inspection gallery is placed in rock foundation downstream of cut-off wall directly below the core, between station 0+950 and 2+342.

The dam construction was started in the year of 1994 and was ended in 2001. Impounding of the reservoir began in February 2000, when the dam was not completely constructed. In 2004 the reservoir reached to its highest level of 210.3 m.a.s.l. during five years of impounding. To date, the reservoir has not been raised to its final normal water level at 220 m.a.s.l.

2. FOUNDATION GEOLOGICAL CONDITION

The geologic chronology of the dam site which belongs to the late tertiary period, with wide range of variation in significant geotechnical properties, mainly consists of conglomerate layers (Mahab Ghodss Consulting Engineers, 1995). The conglomerate is stratified by mudstone layers of 3 to 9 meter in thickness and nearly horizontal. The mudstone layers lying at levels below the river have been given negative numbers (-1, -2 and –3) and those above the river have been marked with positive numbers (1, 2, 3 and 4).

The conglomerate is an extremely irregular accumulation of gravel embedded in a sandy, sandy-silty or silty-clayey matrix, with different degree of cementation. In addition, the "open frame gravel", without any matrix as well as poorly cemented sandstone lenses are present. This open-gravel occurs as flat lenses and also along the steeply inclined lamina of cross-bedding. In overall, the conglomerate layers are divided into 3 types as follows:

Type A - conglomerate with a matrix of silt and clay or calcite (low permeability)
Type B - conglomerate with a matrix of sand (medium permeability)
Type C - conglomerate without the fine-grained matrix (high permeability)

From among the 3 types of conglomerate, the A-type is more than 60% and the B-type is about 35% of the conglomerate at the dam foundation. The C-type conglomerate has a high permeability and as mentioned has been described as “open framework gravel”. Depending on the conformation of conglomerates due to different cementation conditions, the permeability is estimated to be varied between 10^{-5} and 10^{-1} cm/s.

Composition of mudstone layers is also variable between clay rock and sandy–silty rock varying with elevation as well as within one layer. The range of permeability of mudstone is between 10^{-7} and 10^{-4} cm/s. As can be seen, the permeability coefficient of relatively horizontal layers of mudstone is much less than that of conglomerate. The mudstone layers are deposited at different depths. Investigations and observations indicated that these layers are continuous and sufficiently extensive upstream and downstream at the location of dam.

3. PERMEABILITY INVESTIGATION

In this section all investigations performed for determination of Karkheh Dam conglomerate permeability during design, construction and impounding is presented.

3.1. Lugeon Test

Totally 823 Lugeon test at different layers at different locations were performed. The results showed that there are rocks ranging from impermeable to very high permeability in the dam foundation and abutments. It was found that 8 lithologies with respect to permeability exist as summarized in Table 1. In this table the rock type, average permeability in Lugeon unit and the percentage of rock mass are presented.

3.2. Pumping Test

In order to obtain an estimation for average permeability of conglomerate a pumping test was carried out in two conglomerates between mudstones (-1) and (-3). By applying appropriate equation and using the test results such as drawdown in observation wells and the constant discharge, the permeability was computed in two layers at different directions as shown in Table 2. To perform the calculations two different assumptions for the type of flow *i.e.* laminar or turbulent were made.

Table 1. Results of Lugeon tests.

Rock type	Average permeability (Lugeon)	Rock mass percentage
Conglomerate with weak cementation and a matrix of sand (weathered and surficial parts of rock)	60	20
Conglomerate with weak to medium cementation and a matrix of sand	60	7
Conglomerate with good cementation and a matrix of sand	30	11
Conglomerate with weak cementation and a silty sandy matrix	30	17
Conglomerate with weak cementation and a silty-clayey matrix	10	28
Scattered lenses of sandstone in conglomerate	10	3
Mudstone layer	3	12
Open-framework gravel	Very high	2

Table 2. Pumping test results.

Conglomerate layer	Flow type	Permeability(m/s) in direction parallel to dam axis	Permeability(m/s) in direction perpendicular to dam axis
Between mudstone (-1) and (-2)	Laminar	3.95×10^{-4}	4.60×10^{-4}
Between mudstone (-2) and (-3)	Laminar	7.32×10^{-4}	4.71×10^{-4}
Between mudstone (-1) and (-2)	Turbulent	1.50×10^{-6}	1.50×10^{-6}

3.3. Dewatering of Diversion Culvert Stilling Basin

Before construction of main dam body the upstream cofferdam was completed and river was completely diverted through the concrete culvert (Figure 1). During construction of diversion culvert an excavation was made and the area was dewatered by a surface pumping system. The total water discharge of dewatering system along 600 m excavation area was measured to be 340 lit/s. A back analysis was carried out and the permeability of conglomerate was estimated equal to 3.45×10^{-5} m/s.

3.4. HPP Excavation Dewatering System During Trial Impounding

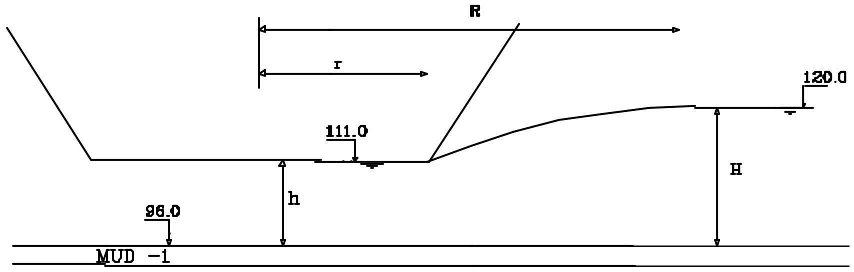
In summer 1997, when the upstream coffer dam was completed and the main embankment was under construction, by closing the gates of diversion culverts the dam body was subjected to a trial impounding. The main purpose was to test the reservoir and foundation condition. The maximum reservoir water level reached to144 m.a.s.l (37 m above river bed) and was drawn down afterwards. In the HPP excavation area, a pumping system was used to remove collected groundwater seepage in order to maintain water level sufficiently low to accommodate construction activities. During the trial impoundment the discharge of dewatering system at HPP excavation area and the lake water level were precisely recorded. The collected data was used in a seepage back-analysis to estimate the permeability of conglomerate rock. Two methods of calculations were employed in this back-analysis.

3.4.1 Well Formula

In the first method, the dewatered excavation area was approximated by a circular hole and a well formula was used for pumping rate estimation (Figure 2). Since in this case the pumping discharge was known the formula was employed to compute the conglomerate permeability. Because the distance R could not be determined exactly, different values for R was assumed and as a result the permeability of conglomerate between mudstones (+2) and (-1) was calculated to be in a range of 1.5×10^{-4} to 8×10^{-4} m/s.

3.4.2. Two–dimensional FEM Seepage Analysis

The mudstone layers are bedded horizontally in the area of the project. Geotechnical investigations and observations indicated that these layers are enough continuous at the location of dam to provide different horizontal strata for each conglomerate layer confined by upper and lower mudstone layers. Due to this condition for each conglomerate layer, the vertical component of seepage velocity except at exit point is negligible. Thus a two-dimensional FEM in horizontal plane was used to model the hydrological situation of conglomerate between mudstones (+2) and (-1). Figure 3 shows the equi-potential lines resulted from the model analysis. By incorporating the measured seepage discharge into the model the permeability was determined. The seepage analysis demonstrated that the permeability of this layer is about 4×10^{-4} m/s which falls into the range of permeability obtained from the well formula. Based on this observation the



$$Q = \frac{pk(H^2 - h^2)}{Ln(R/r)}$$

Q = Water discharge
k=Permeability coef.

Figure 2. Well formula method employed for permeability estimation in HPP excavation area.

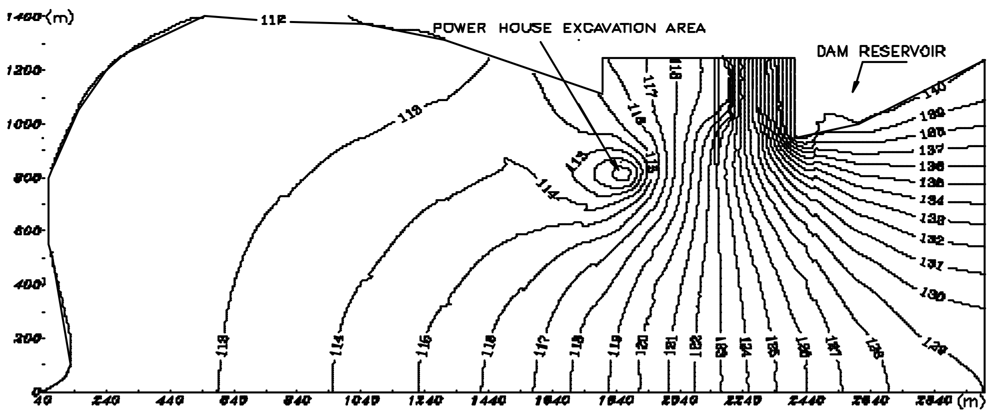


Figure 3.. Equi-potential lines resulted from 2D seepage back-analysis for permeability estimation.

3.5. Observations During First Impounding

The large volume of the reservoir (5.6 billion m^3) would not be filled in the first year of impounding. Filling of the lake started on Feb. 12, 2000 before the dam final completion, when construction works on the right bank and spillway were still going on. So far the maximum lake level reached to 210.5, 9.5 m from full impoundment, as a result of 2004 spring flood. The level of full reservoir during normal operation will be 220m.

By raising the reservoir water level seepage through conglomerate layers of dam foundation and abutments was developed. In order to control, manage and measure the flow discharge and to prevent material erosion a network of channels along with fill embankments were constructed at different locations of seepage springs. Filter and draining materials were used to protect seepage faces from erosion (Mirghasemi *et.al.*, 2004). By taking the advantages of existing seepage collection systems, the volume of seepage through the abutments and foundations was continuously measured.

A three – dimensional ground water model of Karkheh dam was developed using the FEFLOW software. In this model each conglomerate layer was simulated separately. The model calibration and validation was set using the data from seepage discharge measurements and water level readings at piezometers and observation wells locations. The permeability of conglomerates was assessed by the means of 3-D hydrogeological model. In Table 3 the conglomerate permeability for different layers is summarized.

Table 3. Conglomerate permeability obtained from 3D hydrogeological model.

Conglomerate location	Average permeability (m/s)
Above mudstone (+4) at left abutment	5.0×10^{-4}
Between Mudstones (+4) and (+3) at left abutment	7.0×10^{-4}
Between Mudstones (+3) and (+2) at left abutment	7.0×10^{-4}
Above mudstone (+3) at right abutment	8.0×10^{-4}
Between Mudstones (+3) and (+2) at right abutment	5.0×10^{-4}

3.6 Comparison of Permeability Obtained From Different Methods

Table 4 summarizes the different values of conglomerate permeability determined from different methods of investigations.

As can be noticed there is about two order of magnitude differences between the results of investigations performed for conglomerate permeability determination. The values determined from Lugeon tests are much lower than those obtained from other procedures, in which larger volume of rocks are involved, such as pumping test and back-analysis of developed seepage flows during construction and impoundment. It seems that the observed high permeability is likely caused by dominating influence of highly permeable open work gravel which could not be caught in a single point test such as Lugeon. In spite of low percentage of this type of high permeable rock (Table 1), its influence on overall permeability is remarkable. Probably hydraulic connections between permeable and highly permeable zones result in the development of preferred seepage flow paths. The high portion of semi-permeable zones in the conglomerate plays only a minor role in this mechanism.

Table 4. Comparison of permeability coefficients resulted from different procedures.

Method of Investigation	Flow type assumption	Permeability coefficient (m/s)
Water pressure test (Lugeon)	-------	$1.2 \times 10^{-6} \sim 2 \times 10^{-5}$
Pumping test	Turbulent	1.5×10^{-6}
Pumping test	Laminar	$4.0 \sim 7.0 \times 10^{-4}$
Diversion Culvert dewatering system	-------	3.5×10^{-5}
Trial impounding and HPP dewatering system	-------	$1.0 \sim 8.0 \times 10^{-4}$
3D hydrogeological models of upper conglomerate layers during impounding	-------	$5.0 \sim 8.0 \times 10^{-4}$

4. SUMMARY AND CONCLUDING REMARKS

The nature of the Karkheh dam foundation at the dam site is rather complex and non-homogeneous. The geologic chronology of the dam site belongs to the late tertiary period which is mainly consists of conglomerate layers. The permeable conglomerate is stratified by impervious mudstone layers of 2-10 m in thickness.

Many methods, both direct and indirect, have been carried out for determining the permeability of Karkheh dam conglomerate rock during different stages of dam design, construction and impounding. In this paper the results of these investigations were reported and comparisons were made. It was found that permeability values estimated by the methods such as pumping test and back-analysis of observed seepage flows, in which large volume of rocks are included, were 100 times higher than those evaluated by the single point tests (Lugeon). In spite of low percentage of high permeable "open work gravel" zonet of rock mass, it remarkably dominates the overall permeability of conglomerate rock. The hydraulic connections between permeable and highly permeable zones are responsible for the high overall permeability. The high portion of semi-permeable zones in the conglomerate plays only a minor role in this phenomenon.

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