EFFECTIVENESS OF UPSTREAM BLANKET AND GROUTING IN CONTROL OF SEEPAGE AT KHANPUR DAM PROJECT

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ABSTRACT: Khanpur Dam in Pakistan was constructed on deep alluvial deposits underlain by foundation rock. The dam, since its operation in 1983, has predicament of seepage and in spite of several studies and remedial measures taken in this regard, the problem has not been resolved completely. The present study presents a review of performance of different components of Khanpur Dam in the context of seepage. In this research, Geostudio 2004 package has been used to see the effect of different factors on the quantity of seepage and the results have been validated with the help of field data. The research work concludes that upstream blanket is working efficiently and seepage through the main dam has been stabilized due to the strengthening of the upstream blanket because of sediment deposition. Geostudio analysis as well as field data has indicated that previous grout work at left and right abutments has failed to produce the required results and seepage which is being measured at the downstream toe of the dam is through the abutments instead of through the body or foundations of the dam and recommends that by extending the grout curtain up to a depth of 140' in case of left abutment and to a depth of 160' in case of right abutment, the quantities of seepage can significantly be reduced.

Key words: earthern dam, seepage, upstream blanket, grout curtain, alluvium

INTRODUCTION

Seepage control in earthern dams is very important and a slight negligence can lead to catastrophe. Seepage reducing methods make use of relatively impermeable cutoffs, grout curtain and upstream blankets which consume energy at locations within cross sections where large water pressures and seepage forces can have no detrimental effects. The net result is that water pressures and seepage forces are reduced in the critical exit regions (Cedergren, 1980). Selection of seepage reduction measure depends upon site conditions. Generally in dams located on deep permeable alluvium relatively impervious compacted earth blankets are placed upstream of dams and levees to lengthen the seepage path and thereby reduce the exit gradients and the quantity of seepage. Turnbull and Mansur (1961) observed that along Mississippi river valley upper strata of silt and clay form a relatively impervious blanket over older beds of sand and gravels. When dam is to be constructed proper upstream blanket should be provided to control seepage. Similar conditions were observed by Cedergren (1967) along Lower Columbia River, the Willamette river in Oregon, and Sacramento river in California. In Pakistan Tarbela Dam is located on 125 to 215 m deep permeable alluvium layer. The installation of vertical cut off is not considered feasible due to large thickness of the alluvium and high construction cost. However, partial cutoff would not be effective because permeability does not decrease with depth. Therefore to control seepage an impervious blanket 2260 m was provided. (Haq and Rehman 1984). Khanpur Dam like Tarbela is also located on 200 ft deep river alluvium and is provided with upstream blanket to control seepage. In this paper an attempt has been made to critically review the measures taken at Khanpur Dam for effective control of seepage. To achieve the objectives of research, physical inspection followed by detailed seepage analysis of different components of the dam using GEOSTUDIO 2004 was carried out.

Overview of Khanpur Dam: Khanpur Dam Project is located just downstream of the confluence of Haro River and Nilan Kas near Khanpur village about 32 km North of Islamabad. Haro River originates from the hills of Moshipur and in its mountain tract flows through the rocks of different horizons from the oldest formation to the younger ones. The bedrock underlying the region consists of intricately folded and faulted sedimentary rocks ranging in age from Precambrian to Miocene period. The main project features comprise a main dam on the Haro river, three saddle dams on the right and one saddle dam on the left, a gated spillway and an irrigation outlet. A typical cross section of the dam embankment is shown in Fig. 1 and layout of dam in Fig. 2. Khanpur Dam is founded on deep alluvial deposits and has an upstream impervious blanket. The embankment is 1560 ft long at crest level and has a maximum height of 167 ft. It is a zoned section with a chimney drain and drainage blanket (WAPDA 1984).

Khanpur dam was completed in early 1983 and initial filling of reservoir took place up to the spillway crest level in August 1983. The dam, after its first partial impounding in 1983 resulted in loss of storage due to seepage which was alarmingly high, ranging to the limit of 50% of the base flow. To dig out the causes of seepage for Khanpur dam, detailed investigations were carried out in 1993 and as a result excessive seepage quantities were measured along the left abutment. The consultants recommended to strengthen the existing grout curtain and stressed the need of further explorations and drilling to plan and design the grout curtain (WAPDA 1993). The recommendations of the consultants were obliged and further grouting works were performed but still the problem remained unresolved. Therefore the present research was undertaken to carry out seepage analysis through GEO-STUDIO 2004 and compare the results with the field observations.

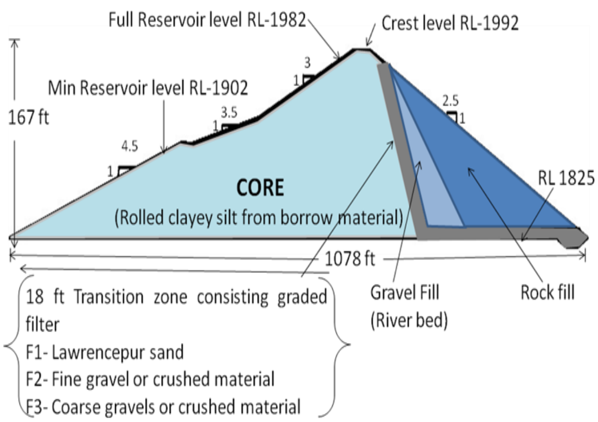

Fig.1 Typical cross section of Khanpur Dam

Fig.2 Layout of Khanpur Dam

MATERIALS AND METHOD

Geotechnical Modeling Using Geo-Studio 2004: Geotechnical behaviour modeling has been performed using SEEP/W which is a finite element software product from Geo-Studio 2004 to calculate the seepage. It is a general seepage analysis program that models both saturated and unsaturated flows. SEEP/W can be used to model the movement and pore water distribution within porous material such as soil and rock. Its comprehensive formulation makes it possible to analyze both simple and complex seepage problems (Krahn 2004). The seepage analysis consists of two steps. The first step is to define and sketch the problem, mesh it and then assigning the permeability values. Approximate k-functions are used for embankment clay core, upstream and downstream shells instead of constant k-values to get a more realistic phreatic line profile in clay core. Boundary conditions for the problem are defined as total head at the base of reservoir, total head at the ground surface downstream of the dam and total flux (zero) across the left and right vertical boundaries and along the base of the dam. After this the model is analyzed.

RESULTS & DISCUSSION

Seepage Analysis of Main Dam: Quantity of water passing through a porous media such as soil is known as seepage. The knowledge of seepage is essential for engineers involved in the design and construction of dams, barrages and other water retaining structures. (Qureshi & Akbar, 1995). Flow net is a prerequisite to carry out seepage analysis and the boundary conditions must simulate actual field conditions (DAS, 1987). Uncontrolled seepage can make the excavation very wet result in loss of strength and increased compressibility. Also, excessive seepage causes stability problems such as heaving, piping and quick sand condition and may even cause liquefaction (Aysen, 2002). Seepage should be controlled by cut-off trenches or by providing upstream impervious blanket (USACE, 1992). However, in case of rock foundations, seepage occurs through cracks and joints and can be controlled by grouting (Weaver, 1993). A filter material is normally provided at the interface between the impervious blanket and rock abutment to control seepage (Widman, 1993). The quantity of seepage downstream of the main dam is shown in Fig 3. The seepage has gradually decreased with time and is presently about 25 percent of the values recorded at the time of commissioning of the project. This is due to accumulation/deposition of reservoir sediments which have strengthened the upstream impervious blanket.

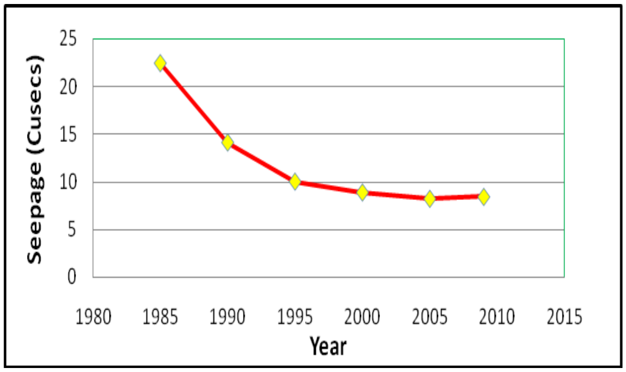

Fig. 3 Seepage Record at R.L = 1980 ft; Main Dam Downstream Toe Area

The seepage analysis of main embankment dam has been performed by taking the effect of sediment deposition. Data from 1985 upto 2010 has been collected and analysis has been carried out to see the effect of deposited sediment on the performance of upstream blanket. The main dam along with 2900 ft long upstream blanket has been modeled on scale as shown in Fig. 4 and material properties has been assigned. The section has been analyzed on maximum reservoir level (R.L) of 1980 ft. above mean sea level.

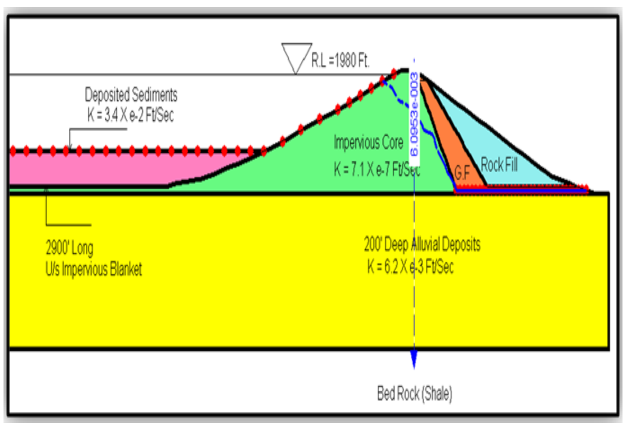

Fig. 4 Results of Analysis of main dam

Six cases were performed and seepage calculated against the sediment deposited during 1985, 1990, 1995, 2000, 2005 and 2010. The values obtained have indicated that upstream blanket is working efficiently and seepage has decreased from 17.56 Cusecs to 3.57 cusecs due to the strengthening of the blanket because of sediment deposition. However the seepage quantity computed, when compared with the actual values of seepage being recorded at site gives quite devastating results for the year 2010 as can be seen from Fig. 5 that actual seepage is significantly higher than the seepage calculated with SEEP/W. The % age difference is approximately about 70%. The % age difference between the recorded values of seepage for main dam and calculated values for the model without abutment is about 70% which is very high indicating the need for the model to be revised.

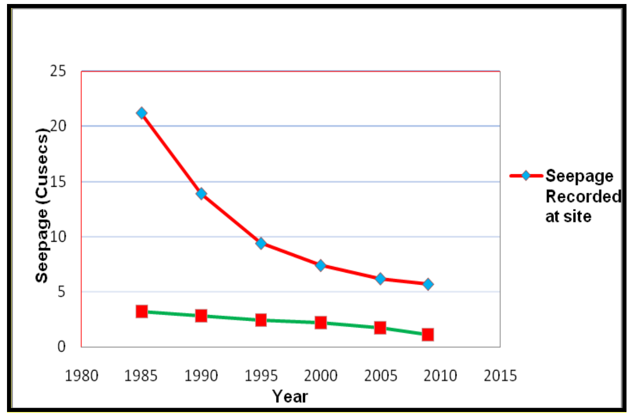

Fig. 5 Comparison b/w actual seepage and values calculated by SEEP/W at Main Dam

To trace the reason of these devastating results, piezometric data has been collected and analyzed. It has been observed that piezometers installed on the left abutment are showing a rising trend and moreover as we move along the dam from left abutment towards right abutment, piezometric level decrease which indicate that there is natural operative hydraulic gradient from left abutment towards right abutment and due to which a part of under seepage from left abutment is also being collected at the downstream of the dam. This is the reason that actual values of seepage are more than double the SEEP/W values because SEEP/W model has not considered the abutment effect. To validate this presumption, another section of the dam has been modeled along with left abutment as shown in Fig. 6. Three different types of limestones layers present along the left abutment are argillaceous limestones (L_a), massive limestone (L_m) and nodular lime stone (L_n) and indicated in Fig. 6.

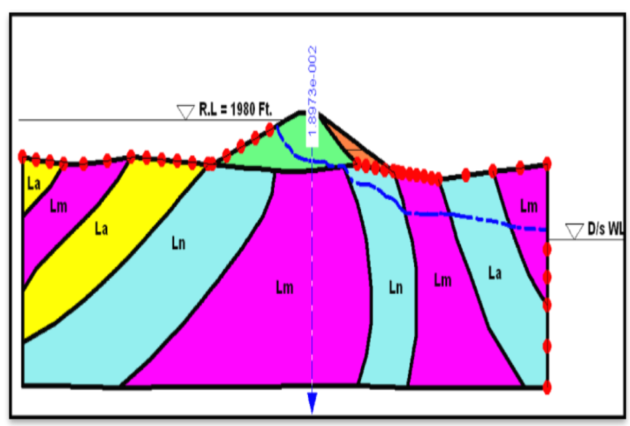

Fig. 6 SEEP/W model of main dam alongwith Left abutment

Fig.7. presents a comparison b/w the actual values of seepage measured at site and seepage values calculated using SEEP/W for the model with and without abutment. However, by taking the effect of abutment the results come closer to the actual values and % age difference is only 7.5%, hence it can be inferred that part of seepage, which is being measured at the downstream of the main dam is from left abutment.

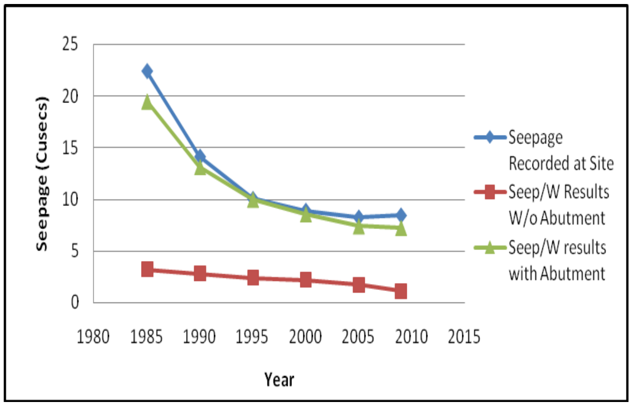

Fig 7: Comparison b/w values calculated by SEEP/W and actual seepage at site

Seepage Analysis of Left Abutment: Limestone beds are believed to be major conduits of seepage. They extended from upstream towards downstream over the left abutment forming an inverted syncline which sinks towards downstream with its apex at the Nilan Khas. These beds are between elevation EL 1860 ft and EL 1880 ft almost 20 to 40 ft below the dead storage level. Limestone bed is exposed in the form of steep ridge between EL 1875 ft and EL 1910 ft for about 800 ft length upstream of diversion tunnel portal appears to be left untreated due to inaccessibility. Similarly, no treatment was possible for limestone bed located on the left bank of Nilan Khas in the shape of 20 to 25 ft high cliff. The seepage collected in the diversion tunnel is measured at its outlet portal. The seepage emerging from the left ridge of Haro river downstream is collected and measured separately. These two seepage volumes are combined to calculate the total left abutment seepage. The recorded seepage at left abutment at various reservoir levels is presented in Table 1 and will be compared with the values obtained by SEEP/W analysis. The seepage had shown an increasing trend upto the year 1997-1998 and it had increased by 60% to 75% for reservoir level El 1940 ft to El. 1960 ft. However, in the year 2003 this trend was reversed and measured seepage was close to the 1993 values. This could be due to the grouting which was executed in the period 1999 to 2002 under Khanpur Safety Works (KSW). During the present study left abutment seepage data indicates an increasing trend with values again touching the 1997/1998 values.

Table: 1 Seepage Record at Left Abutment

Sr. No.	Year	1985	1990	1995	1998	2003	2010
	Res. Level	Seepage (Cusecs)					
1.	1930'	5.1	6.3	6.9	8.1	7.1	8.7
2.	1940'	5.7	7.2	7.8	9.2	8.1	9.5
3.	1950'	6.5	8.1	9.3	10.7	9.6	10.1
4.	1960'	7.1	8.7	10.6	11.37	10.45	11.2
5.	1970'	7.6	9.2	11.4	13.42	11.2	13.6
6.	1980'	8.37	10.9	12.7	15.36	12.54	14.96

In order to evaluate the performance of grout work carried out at the left abutment, the section of the left abutment has been modeled on SEEP/W and analyzed under existing boundary conditions. Fig. 8 represents the SEEP/W model for left abutment without considering grouting. It was observed that without grouting the seepage value calculated by SEEP/W model is 9.89 cusecs where as recorded value at site is 12.54 cusecs. Similarly, two more cases were modeled by considering grouting upto 100 ft and grouting upto 140 ft to find out optimum length of grout. The results of seepage analysis are presented graphically in Fig. 9 and summarized in Table 2.

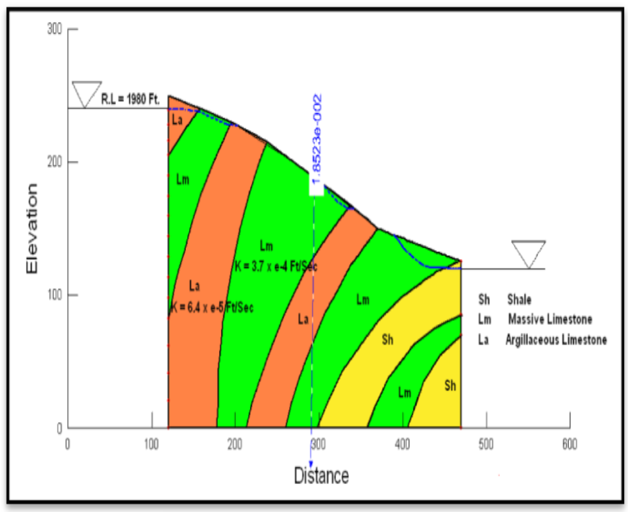

Fig. 8 SEEP/W model of left abutment (without grouting)

It can be inferred from Table 2 that the existing grout curtain has not proved effective in controlling the seepage through the left abutment. Hence the depth of grout curtain should be increased and analysis by SEEP/W has indicated that by extending the grout curtain upto the impervious shale bed, the seepage can be significantly reduced i.e. 9.89 to 3.9 cusecs.

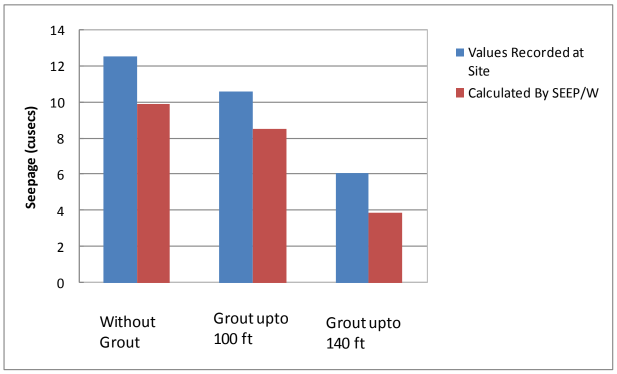

Fig. 9 Comparison between recorded and calculated values of Seepage at Left Abutment

Table 2 Comparison between recorded and calculated values of Seepage at Left Abutment

Case No.	Description	Depth of Grout Curtain	Seepage Recorded at site (Cusecs)	Seepage Calculated with Seep/W (Cusecs)
I	Without Grout Curtain	N.A	12.54	9.89
II	Existing Conditions	100'	10.64	8.56
III	Suggested	140'	6.1 (Interpolation)	3.9

SEEP/W Analysis of Right Abutment: The seepage form Main Dam, the right abutment and the spillway is measured collectively at the Spillway plunge pool. A part of seepage in the river alluvium contributed by the underlying bed rock is also collected at the plunge pool. Seepage measurement record of plunge pool is very unpredictable as spillway was functioning quite frequently since first impounding since 1983. No significant effect of grouting has been noticed on seepage. The seepage in the plunge pool area as measured in year 2007 is almost double than the measured values of year 1990. The available seepage data is shown in Table 3 and it will be compared with the analysis values.

Table 3 Seepage Record at Right abutment

Sr. No.	Year / Res. Level	1985	1990	1995	2000	2005	2010
		Seepage (Cusecs)					
1.	1930'	6.7	7.2	7.5	8.1	7.6	7.1
2.	1940'	7.9	8.7	9.3	9.7	8.9	8.2
3.	1950'	8.7	10.7	11.1	11.6	10.5	9.9
4.	1960'	10.9	13.4	13.9	14.3	12.7	11.9
5.	1970'	12.7	14.1	15.6	16.7	13.3	12.8
6.	1980'	14.3	16.3	17.3	19.4	15.6	14.9

In order to evaluate the performance of grout work carried out at the right abutment, the section of the right abutment has been modeled and analyzed under existing boundary conditions. Fig. 10 represents the SEEP/W model used for analysis of right abutment without grouting. Seepage value calculated by SEEP/W analysis is 16.67 cusecs. Similary, two more cases were considered i.e right abutment with grouting upto 120 ft and right abutment with grouting upto 160 ft to find out the optimum length of the grout curtain. The results of these case for right abutment are presented in Fig. 11 and are summarized in Table 4

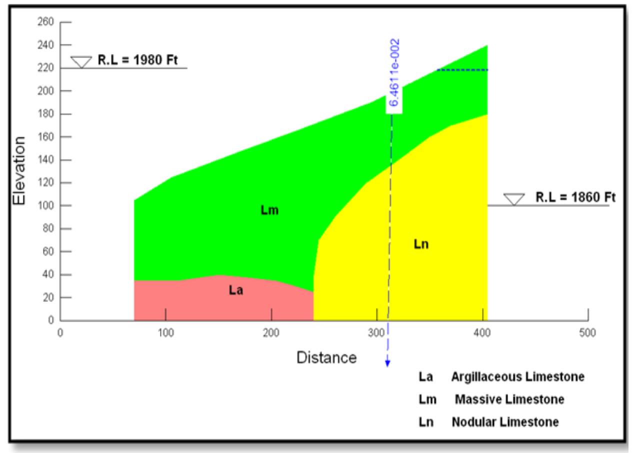

Fig. 10 Seep/W model of right abutment without grouting

It can be seen from the above table that the existing grout curtain has not proved quite effective in controlling the seepage through the right abutment. Hence the depth of grout curtain should be increased and analysis by Seep/W has indicated that by extending the grout curtain upto 160', the seepage is significantly reduced i.e. from 16.67 to 2.2 cusecs.

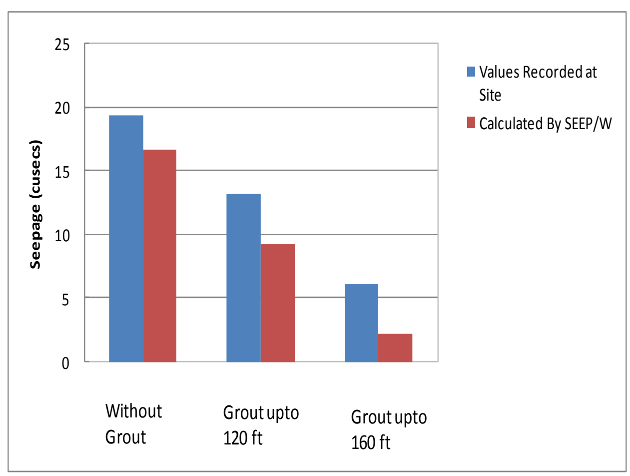

Fig. 11 Comparison between recorded and calculated values of Seepage at Right Abutment

Table 4 Comparison b/w recorded and calculated seepage at right abutment

Case No.	Description	Depth of Grout Curtain	Seepage Recorded at Site (Cusecs)	Seepage Calculated with Seep/W (Cusecs)
I	Without Grout Curtain	N.A	19.4	16.67
II	Existing Conditions	120’	13.2	9.35
III	Suggested	160’	6.3 (Interpolation)	2.2

Conclusions

- Seepage Analysis indicates that upstream blanket is working efficiently and seepage downstream of the dam has decreased from 17.56 cusecs to 3.57 cusecs due to the strengthening of the blanket as a result of self healing process and due to the effect of sediment deposition.
- At Left Abutment, previous grouting has not produced the required results and seepage at Reservoir level 1980 ft has decreased marginally i.e. from 9.89 to 8.56 Cusecs. Seepage Analysis by SEEP/W has shown that by extending the grout curtain into the impervious shale bed, it is reduced to 3.9 cusecs.
- In case of right abutment, seepage under existing conditions at Reservoir level 1980 ft has been observed to decrease from 16.67 to 9.35 cusecs but still greater than left abutment and needs attention. It is however anticipated, based on analysis that it would be reduced to 2.2 cusecs by extending the grout curtain upto a depth of 160'.

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