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Evaluation of Performance of Plastic Concrete Cutoff Wall in Karkheh Dam Using 3-D Seepage Analysis and Actual Measurement

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Abstract: In this study, first the integrity of the plastic concrete cutoff wall in Karkheh dam is sought by reviewing constructional controls and observations. Then, the performance of the wall before the extension is modeled using SEEP 3-D computer code and calibrated using actual seepage measurements. The future performance of the wall when reservoir reaches its maximum level is also predicted. At last the effect of extension of the wall on the seepage using 3-D model is presented. According to the results of this study the integrity of the wall itself is warranted. The considerable seepage observed after impoundment was mainly due to partially penetrated cutoff wall in the left and right abutments. Three dimensional prediction of seepage after construction of a completely penetrated wall in the left and right abutment and impervious blankets indicates decrease in seepage by 20-60% in right and left abutment, respectively.

Key words: Bentonite concrete cut off, conglomorate, mudstone, well points, earth core, rockfill

INTRODUCTION

Although design and construction of large dam go back to several decades, this issue is still attracting interest of research and engineering institutes around the world. Dunbar and Sheahan (1999) explains remediation seepage control at Hodges village dam. Xing *et al.* (2006) explained construction of concrete faced rockfill dams with weak rock. Indraratna and Raut (2006) introduce an analytical procedure for obtaining particle distribution of selffilteration soils. Kakuturu and Reddi (2006) evaluated experimentally the parameters influencing self healing in earth dams. Wan and Fell (2004) examine rate of erosion of soils in embankment dam using the slot and the hole tests. Bendahmane *et al.* (2008) studied backward erosion in dam using new experimental device that can apply hydraulic stresses to cohesive soils without cracks in order to characterize the erosion evolution processes that might be present. Wan and Fell (2004) assessed the potential of internal instability in embankment dams and their foundations based on laboratory tests carried out by the writers and results published by others. Fell *et al.* (2003) introduced a method for prediction of time for development of internal erosion in dams.

Several studies sited in the literature deal with designing , construction and performance of diaphragm cut off walls in dams. Brown and Bruggeman (2002) describe the foundation seepage cut-off made of plastic concrete in Arminou dam in Cyprus. In this study the main factors governing the effectiveness of diaphragm walls as seepage cut-offs including construction joints, hydraulic gradients and hydraulic fracture are discussed. Bagheri *et al.* (2008) examined experimentally the use of silica fume in plastic concrete cut-off walls in order to reduce the permeability.

Karkheh dam located on the Karkheh river in southwest of Iran in the Khuzestan Province. It has a length of 3030 m and a height of 127 m (above its foundation) and it is a rock fill dam with central clay core. Figure 1 shows a general plan view of the dam. A plastic concrete cutoff wall extends about the full length of the dam in the foundation. Karkheh dam cut-off wall with a length of 2940 m and area of 190000 m^2 is one of the largest plastic concrete cutoff walls in the world. At the beginning of reservoir impoundment, considerable seepage in the left and right downstream abutments were observed and recorded. This could have been either due to defects in the wall or due to lack of complete cutoff to the lower impervious mudstone in these regions. In order to decrease the amount of seepage and thus increasing the safety of the dam, extension design of cutoff wall penetrated completely to the lower impervious mudstone is under construction. This increases the area of the wall to 350000 m^2.

In this study the integrity of the cutoff wall is sought by reviewing constructional controls and observations

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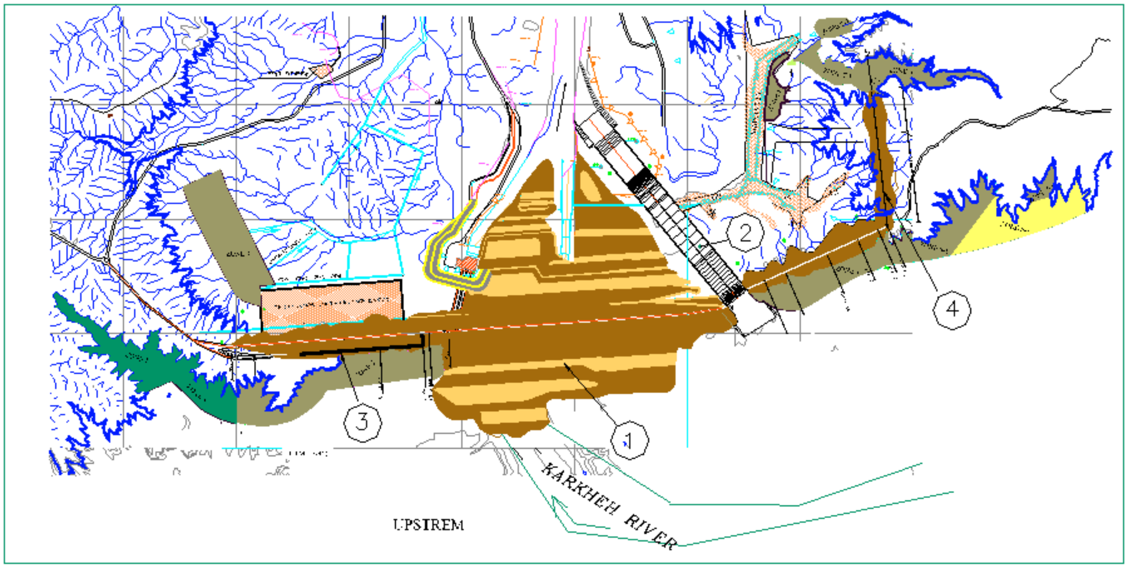

(1) Body of dam (2) Spillway (3) New left bank c.o.w (4) New right bank c.o.w

Fig. 1: General plan of the Karkheh dam

made during the construction. The prediction of future seepage when the reservoir reaches its maximum level is made by 3-D analysis of seepage in the left and the right abutments. The effect of new extension of the cut-off wall on the seepage is also evaluated.

Geology: The Karkheh dam is located in Southwest zone of Zagros fold. The geology of the dam site consists of conglomerate of Bakhtiari formation with alternate inter layers of mudstone. In general seven layers of mudstone in between the conglomerate exist which according to being below or above the local water level are numbered as -3,-2,-1,+1,+2, +3 and +4 unit. Figure 2 shows a longitudinal cross section of the dam with its foundation geology. In Fig. 3 and 4 a longitudinal profile of the left and the right abutments are shown, respectively. As it is shown in these regions the cutoff wall at some distance is only partially penetrated the conglomerate. At the main section of the dam the wall is penetrated completely to the impervious mudstone layers.

Pump in tests were performed on lower units of conglomerate located below the local water table. The value of the coefficient of permeability of this unit measured in pump in tests was in the range of about $1\text{-}2\times10^{-2}$ cm sec^{-1}. At the design stage this value was used for the upper conglomerate units below the left and the right abutments as well. Later evaluation during calibration of the computer model indicated that this value of the coefficient of permeability for the upper unit is underestimated.

Constructional controls and observations: In order to evaluate the integrity of the plastic concrete cutoff wall of the dam the constructional controls and observations made during the construction are reviewed here.

Excavation of material were done using a hydrofrez excavator BC30 manufactured in Germany. This equipment can excavate a trench with length of 2.8 m and maximum depth of 100 m and with thickness of 64-120 cm. Bentonite slurry is used during excavation in order to maintain the stability of trench wall. The deviation from the vertical direction is critical and the allowable deviation was 2% of the depth of excavation which is taken into account by overlapping between the primary and secondary panels. Excavation of material and concrete pouring were done for primary panels and then after concrete setting in the primary panels, the secondary panels were excavated and concreted with considering of overlapping (for example, in the panels with about 70 m, depth overlapping is observed 30 cm).

Plastic concrete with high slump and workability were poured using Tremie method. Following controls were made during construction in order to make certain that a proper product was obtained:

- Insure tremie pipes coupling seal
- Insure the requirement for min. and max. length of pipes

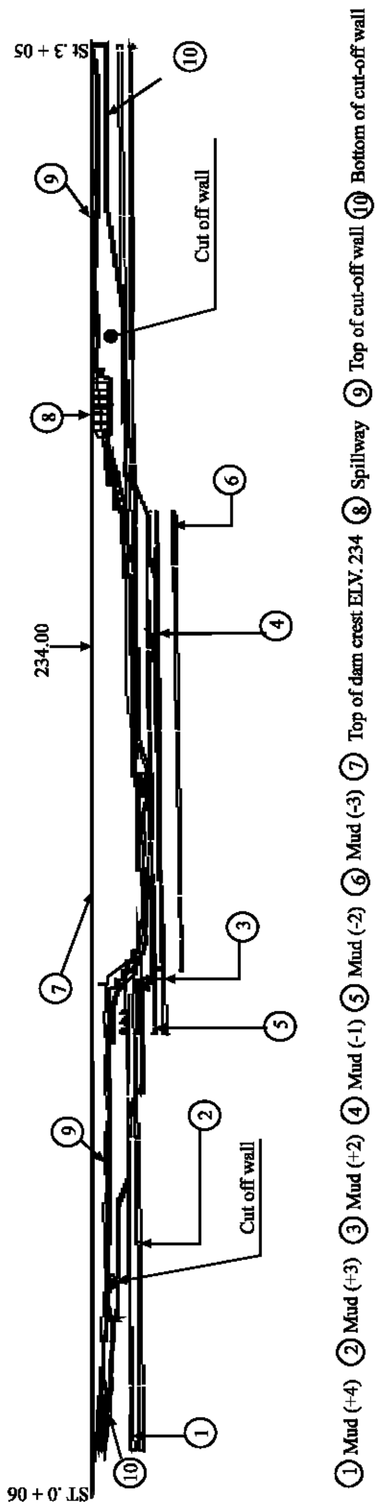

Fig. 2: Longitudinal profile of the Karkheh dam

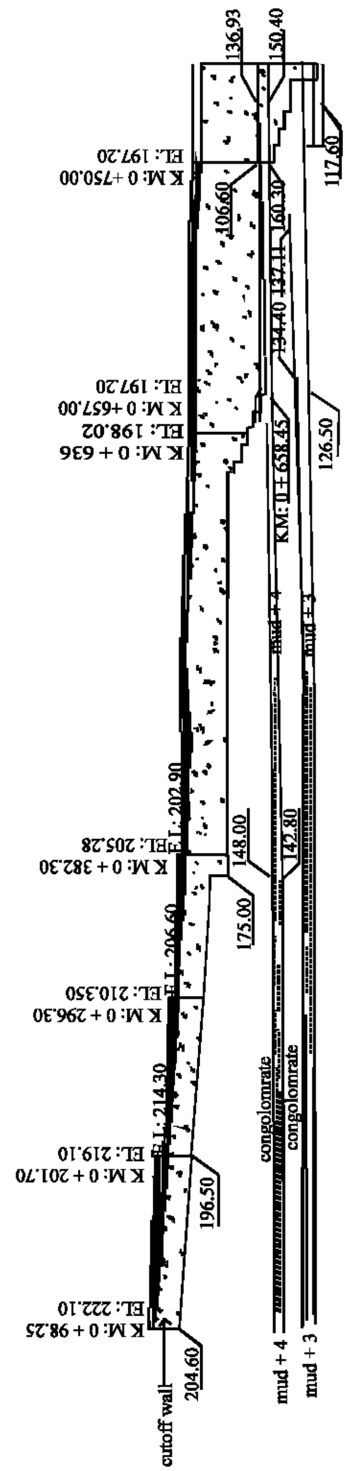

Fig. 3: Longitudinal profile of the left abutment

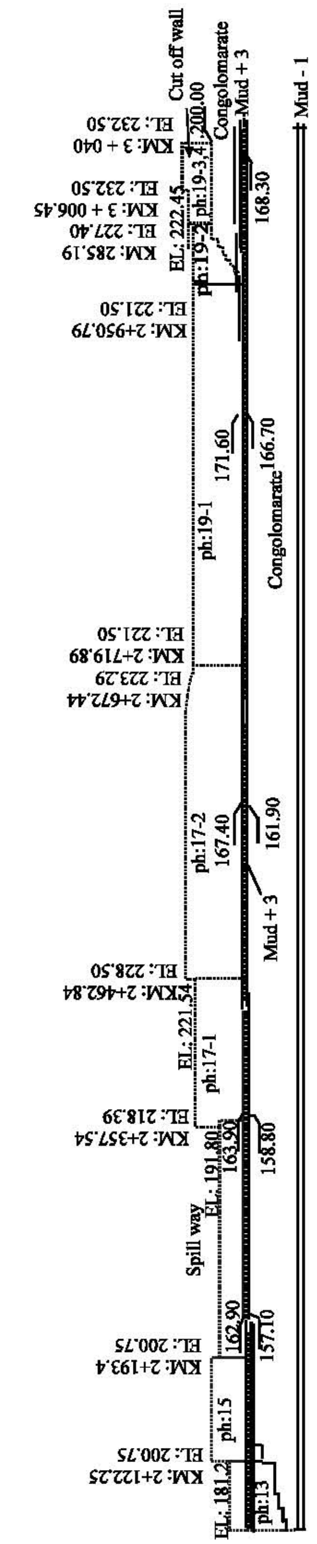

Fig. 4: Longitudinal profile of the right abutment

- Insure allowable distance between the pipe and the bottom of trench
- Insure technical specification of slurry before concrete pouring
- Insure use of a transition in tremie pipe before concreting for preventing mixture of slurry and concrete

A sample of plastic concrete mix used in Karkheh dam is shown in Table 1. Other controls for insuring proper quality of concrete during construction were determination of coefficient of permeability, deformability and compression strength of which typical values are 10^{-6} cm sec^{-1}, 1500 and 3 MPa, respectively.

One of the important aspect of plastic cutoff wall that raised some concern during the construction of Karkheh dam was development of so called bentonite joints between the primary and secondary panels. The concern about these joints was due to this fact that the erosion of bentonite between panels increases the permeability of the wall with time (Soroush and Soroush, 2005). Since the development of these joints was inevitable, in this study, the efforts were to decrease the thickness of these joints. In this regard, following actions were taken in order to achieve the above goal:

- The use of very dilute slurry during excavation of secondary panels
- Shortening of the time between excavation and concreting of secondary panels
- Shortening of the time of excavation and concreting of secondary panels
- Gradual injection of water in excavation zones in order to lower suction
- Use of special devices such as stiff brush before concreting secondary panel
- Use of mix design with low cement for primary panels
- Control the characteristics of slurry such as density, viscosity and pH during concreting secondary panels

Observation of bentonite joints during excavation of water tunnels of the power house indicated that the thickness of joints were less than 5 mm, but two of these joints at location of tunnel 3 at primary panel No. P161 had thickness of 15 mm. All of joints were filled with compacted bentonite cake. These observations lower the concern about the condition of these joints.

Table 1: Materials coefficient of permeability used in the analysis

Material	k_x (m sec^{-1})	k_y (m sec^{-1})
Clay core	10^{-8}	10^{-9}
Shell	10^{-5}	10^{-6}
Mudstone	5×10^{-8}	5×10^{-9}
Cut off wall	10^{-8}	10^{-8}

In addition to the above controls and observations made during construction to insure the integrity of the wall, the quality of the plastic concrete in regard to strength, deformability and coefficient of permeability were checked by testing core samples obtained from the wall.

Evaluation of performance of main cutoff: The performance of the cutoff wall at each level of reservoir has been evaluated by two methods:

- Measurement of water level in observation wells in downstream
- Measurement of seepage in constructed canals with overflow weirs

For levels which the reservoir has not yet experienced the seepage can be predicted using a computer program such as SEEP 3D.

The SEEP 3D computer code solves seepage problems in three dimensions. It gives the user the opportunity to model the problem using graphical methods. The user can perform things such as upgrading, downgrading, determining the scale and etc. The code solves the seepage problem using finite element. The steady and unsteady seepage through the dam body and its foundation in saturated and unsaturated states can be modeled.

The analysis of the seepage in SEEP 3D begins with modeling the geometry of the problem. At this stage, topographical maps, cutoff wall section maps and geological section maps that include geological layering are used. Before creating the geometric model, zoning are done manually on the topographical map in which octagon, pentagon and cubic blocks are determined. By determining overall condition of blocks in topographical map and considering longitudinal section of the cutoff system and geological layering, the regions of the problem can be created. At this stage, locating downstream valleys that are important in the analysis must be determined more carefully. It should be noted that the smaller the dimensions of the blocks chosen in the analysis makes the model acts like the actual case. But by increasing the number of blocks, the execution of the program takes very long time. In order to decrease the execution time, the left and the right abutments were modeled and analyzed separately. The analysis for the main body of the dam and its foundation because of very low permeability and low seepage observed were not performed. Figure 5 shows a complete model after geometric blocking and finite element meshing. One of important stage of each analysis is determination of boundary conditions. In this stage boundary conditions in the boundaries of the problem is added to the system. Boundary conditions include, water level upstream and downstream, impervious boundaries (in the case of

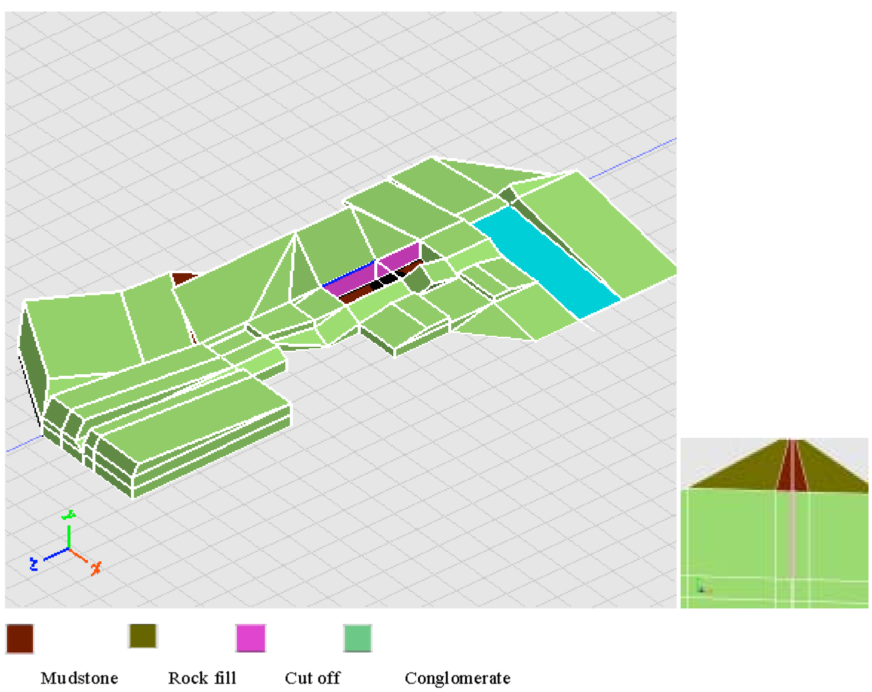

Fig. 5: Zoning in 3-D SEEP analysis of conglomerate above mudstone +3 in the right abutment

Karkheh dam mudstone layers between conglomerate because of low permeability ($k_z = 10^{-7}$ cm sec^{-1}) were indicated as impervious boundaries) and water level in discharge areas in downstream such as springs.

Another stage in the analysis after preparation of model is applying material characteristics such as permeability and degree of saturation to the model. It should be noted that during calibration stage, the permeability of conglomerate were changed in order to match the result of the model to the actual condition. The material properties for different section of dam and its foundation is shown in Table 1.

In the calibration stage of the analysis, the coordinates of observation points is added to the model and the information of these points such as water level obtained in the analysis is matched to the information in observation wells downstream. The permeability of the conglomerate was then changed until convergence between the calculated and measured values in the observation points is reached. In the final analysis the values of permeability of 7×10^{-2}, 5×10^{-2} and 3×10^{-2} cm sec^{-1} was used for the conglomerate layers above 210, between 200-210 and below 200 m levels, respectively in the left abutment. The final values of permeability used in the analysis for the right abutment were slightly higher than those used for the left abutment. These values were 1.1×10^{-1}, 8×10^{-2} and 5×10^{-2} cm sec^{-1} for above 210, between 200-210 and below 200 m levels, respectively.

The results of analysis and actual measurement of seepage for three levels of 200, 205 and 207.6 and also the prediction of seepage for the level 220 by the model for the left and right abutments are shown in Fig. 6 and 7, respectively. In Fig. 6 and 7, the prediction of seepage for the level of 220 using 2-D MSEEP computer program is also included which indicates the inaccuracy of the 2-D analysis in predicting the seepage in this case.

The effect of extension of cutoff wall on seepage: As it can be shown in Fig. 3, the cutoff wall in left abutment for a distance of about 660 m is not completely extended to the impervious mudstone (+4) and (+2) units. Another word it is a partial cutoff. The high rate of seepage measured in this area is due to this fact. In order to decrease the seepage in this area, the construction of an extension cutoff wall completely penetrated the mudstone (+4) and (+2) units is under construction. In addition to this, the construction of impervious blankets in upstream and downstream valleys is also under construction.

The effect of construction of completely penetrated cutoff wall with the length of 358 m (from sta 0+300 to sta 0+658) in upstream side of the main wall (Fig. 1) and the impervious blanket in the left abutment on the amount

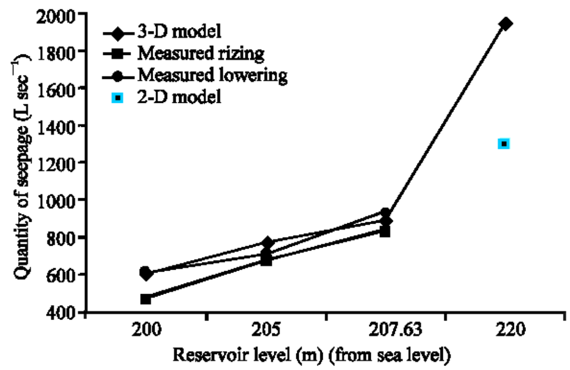

Fig. 6: Comparison of the measured seepage with the prediction of 2-D and 3-D model in the right abutment

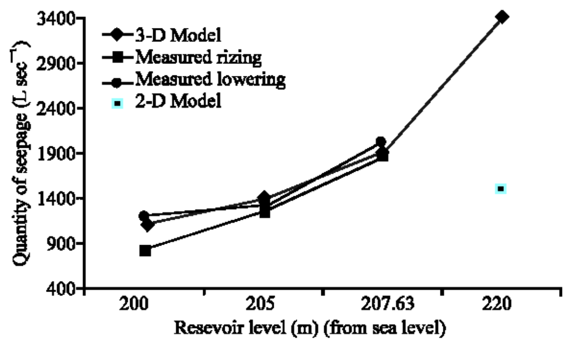

Fig. 7: Comparison of the measured seepage with prediction of 2-D and 3-D model in the left abutment

of seepage for the maximum level of 220 using SEEP 3D model indicates 60% decrease.

The construction of extension of the cutoff wall in the right abutment that penetrates completely into the mudstone (+3) unit for the length of 260 m in the downstream side of the main wall and perpendicular to it (Fig. 1) is also under construction. The effect of this on the seepage was analyzed using SEEP 3D. The result of this analysis for the max level of 220 indicates 20% decrease in the amount of seepage.

CONCLUSIONS

The construction of main plastic concrete cutoff wall in Karkheh dam was performed under controlled conditions. These controls during construction and observations made after construction of the wall together with continuous testing of the core samples obtained from the built wall indicated the integrity of the wall. The considerable seepage observed after impoundment was mainly due to partially penetrated cutoff wall in the left and right abutments. Three dimensional seepage analysis using finite element method predicted very well the observed behavior. The decrease in the seepage after construction of a completely penetrated wall in the left and right abutment and impervious blankets predicted using 3D computer code is 60 and 20%, respectively.

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