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SEEPAGE THROUGH DIFFERENT CONCRETE CUT OFF WALL CONNECTION SYSTEMS
CASE STUDY: KARKHEH STORAGE DAM

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ABSTRACT

Seepage and water flow is one of the most important factors in design of embankment dams. The seepage through the foundation of earth dams can be controlled using the concrete cut off walls. The hydraulic head reduces in connection zone of the cut off wall and core of the dam that results to high hydraulic gradients. As a result, erosion and water leakage may occur. In this regard, the design of concrete cut off wall connection to the clayey core of earth dam is important. In this research, the total flow and the hydraulic gradient are considered to study the seepage through different cut off wall connection systems. The Karkheh storage dam with a plastic concrete cut off wall is selected for the seepage analysis. Six different connection systems are modeled and the effect of physical and mechanical factors like, the cut off wall permeability and the geometry of the connection systems on the total flow and the maximum hydraulic gradient are investigated. The connection systems with minimum flow and hydraulic gradient are determined. According to the results, the cut off wall connection system is an important part that affects the flow in earth dams. In this regard, the connection system with the most effective characteristics and suitability in construction is determined.

INTRODUCTION

There are different ways for the seepage control in foundation of earth dams. The cut off walls are known as one of the useful methods for sealing against water flow in dams, dikes or canals (Shahbazian Ahari, 1999). The cut off walls can be divided to four categories:

- Slurry trench cut off wall
- Bentonite-cement cut off wall
- Concrete cut off wall
- Plastic concrete cut off wall

The difference between these systems is only in the material type. Different systems may be used according to the time and cost limitations by the designer.

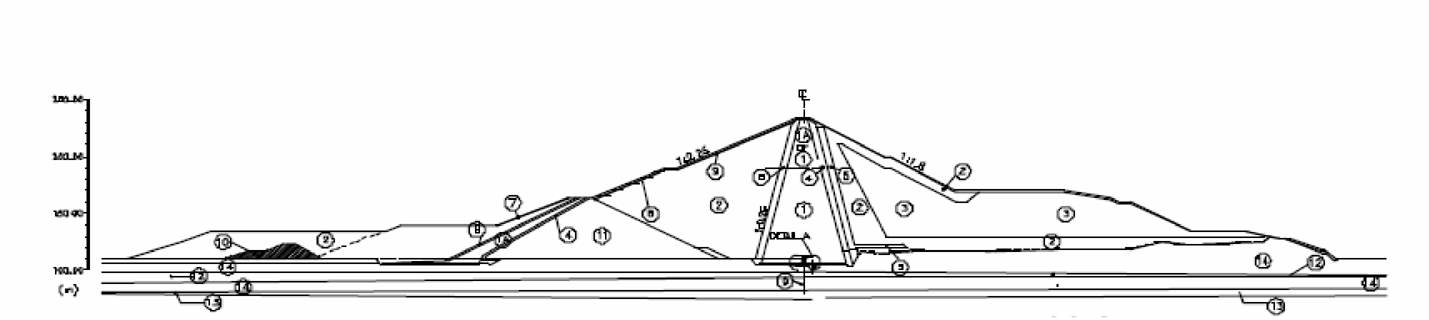
The cut off walls are usually used in high dams with large hydraulic gradients. It is constructed from materials with high mechanical resistance and durability against erosion. These walls should have high deformability to resist induced strains of different mechanical or hydraulic sources without crack or failure. The plastic concrete is an appropriate kind of material for this purpose (ICOLD, 1985). The cut off wall construction causes an increase in hydraulic head at the upstream and a reduction in downstream part of foundation. As a result, the maximum gradient happens in connection of the cut off wall and core (Shahbazian Ahari et al., 2000). The maximum gradient should be less than an allowable limit. The connection system should be designed to satisfy this criterion. This may be reached by different details for connection system as follows:

- Penetration of the cut off into the core
- Thick concrete slab at the base level of the core
- Combination of cut off penetration into the core and the concrete slab
- Compaction grouting around the connection zone in foundation
- Clayey soil besides a concrete cap
- Clayey trench

In the present study, numerical modeling is used to investigate the seepage through different connection systems. The maximum hydraulic gradient and total flow are considered as two major parameters for analysis. The objective of this paper is determination of the most appropriate connection when cut off wall is used as a seepage control system.

CASE STUDY

The Karkheh storage dam is located at North West of Andimeshk in Khoozestan, Iran. This dam is built on Karkheh river which is among the largest ones in Iran, with a high flow discharge. The reservoir capacity is about 5600 million cube meters. The height of the dam is about 127 meters. The dam crest is located in +234 MSL and the minimum level of the foundation is +106 MSL. The normal water level is in +220 MSL. The earth dam has a vertical clayey core and a plastic concrete cut off wall for the seepage control. The maximum and average cut off wall depths are 80 and 40 meters respectively. The foundation consists of conglomerate and mudstone layers. The conglomerate layers have more horizontal permeability compared to the mudstone layers. The different parts of the dam and the foundation are shown in Fig. 1. Table 1 shows the horizontal and vertical permeability values for different parts of the dam, foundation and cut off wall (Shadravan et al., 2004 and Karkheh Dam Section Engineers, 1998).



1. Impervious core (mudstone mixed with sandy gravel)
1A. Impervious core (mudstone)
2. Sandy gravel
3. Conglomerate or sandy gravel
4. Sand filter
5. Gravel filter and drain
6. Sand-gravel filter
7. U/S slope protection using limestone riprap
8. U/S slope protection using soil cement
9. Plastic concrete cut off wall
10. Pre-coffer dam
11. Main cofferdam
12. Mudstone No. (-1)
13. Mudstone No. (-2)
14. Conglomerate
15. Inspection gallery

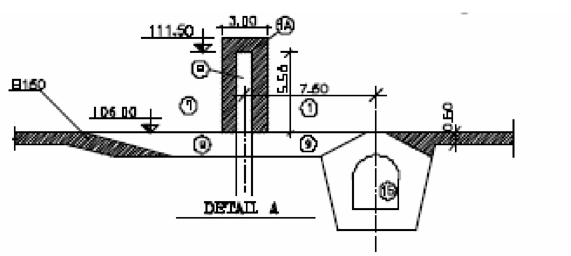


Fig. 1. Cross section of Karkheh storage dam (Karkheh Dam Section Engineers, 1995)

Table 1. The permeability of different parts of the dam

Permeability	Shell	Core	Filter	Cut off	blanket	Alluvium layers	Conglomerate layer (1)	Conglomerate layer (2)	Conglomerate layer (3)	Mudstone layers
K (cm/s)	10^{-4}	5×10^{-7}	10^{-3}	10^{-7}	5×10^{-8}	10^{-3}	45×10^{-3}	5×10^{-8}	11×10^{-4}	6×10^{-4}

NUMERICAL MODELING

The dam, foundation and seepage control system were modeled in the largest section. In this section, the cut off wall continues 25.5 meters below the core and is fixed in a mudstone layer. Figure 2 shows the finite element mesh used in the seepage analysis. The soil anisotropy is modeled using different permeability coefficients in horizontal and vertical directions. The total flow and the maximum hydraulic gradient were determined for different cut off wall connection systems.

Figure 3 shows the details of six connections systems considered in numerical modeling. All the connection systems are numbered. These numbers are representative of each connection system in this study. The variables considered in numerical modeling are shown in each figure and their values are shown in Tables 2-a to 2-f. The following assumptions are considered in numerical modeling.

- The cut off wall width is considered 1 meter in all cases. Only in the first system, the cut off wall width is variable.
- The permeability of the concrete slab and the cut off wall is considered equal in the second and third systems.

- The thickness of concrete slab is considered 1 meter in the third system.
- The permeability is considered to be constant over the grouted zone in the fourth system.
- The cap has 3 meters length from both sides and a thickness of 1 meter in the fifth system. The cap angle is 30° and its permeability is considered equal to the cut off wall.
- The trench width is 3 meters in bottom and the slope of its walls is 3V:1H.

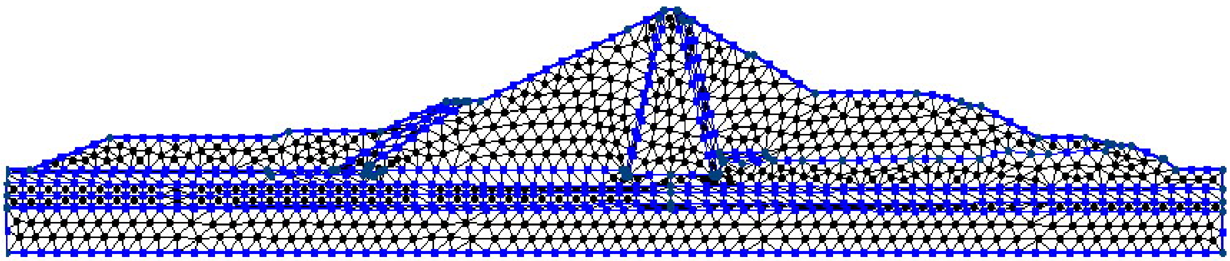


Fig. 2. Finite element mesh generated for the dam

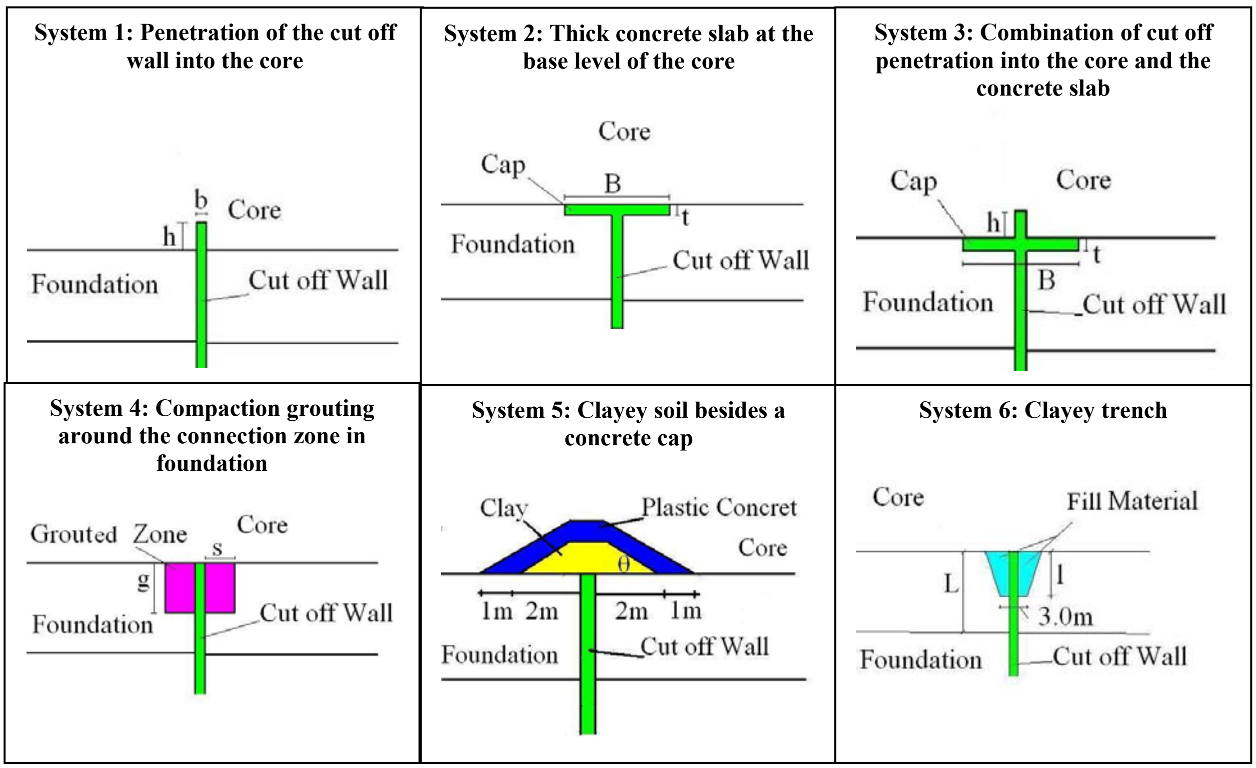


Fig. 3. Different connection systems

Table 2-a. The variables considered in connection system 1

Variable	System 1
b (m)	0.8, 0.9,1.0, 1.1,1.2
h/H	0, 1/30, 1/15, 1/10, 1/9, 1/8, 1/7, 1/6, 1/5
$K_{cut\ off\ wall}$ (cm/s)	1×10^{-8}, 1×10^{-7}, 1×10^{-6}
Number of analysis	135

Table 2-b. The variables considered in connection system 2

Variable	System 2
B (m)	4, 6, 8, 10, 12, 14, 16, 18, 20
t (m)	0.5, 1.0, 1.5, 2.0
Slab locations	in the foundation , in the core, between core and foundation
$K_{cut\ off\ wall}$ (cm/s)	1×10^{-8}, 1×10^{-7}, 1×10^{-6}
Number of analysis	324

Table 2-c. The variables considered in connection system 3

Variable	System 3
B (m)	4, 6, 8, 10
h/H (m)	0.5, 1.0, 1.5, 2.0
Slab location	in the foundation , in the core, between core and foundation
$K_{cut\ off}$ (cm/s)	1×10^{-8}, 1×10^{-7}, 1×10^{-6}
Number of analysis	216

Table 2-d. The variables considered in connection system 4

Variable	System 4
s (m)	2, 3, 4, 5
g (m)	2, 3, 4, 5
$K_{grouted\ zone}$ (cm/s)	5×10^{-8}, 1×10^{-7}, 5×10^{-7}, 1×10^{-6}, 5×10^{-6}, 1×10^{-5}
$K_{cut\ off}$ (cm/s)	1×10^{-8}, 1×10^{-7}, 1×10^{-6}
Number of analysis	288

Table 2-e. The variables considered in connection system 5

Variable	System 5
θ (degree)	30, 45, 60
K_{clay} (cm/s)	5×10^{-8}, 5×10^{-7}, 5×10^{-6}
$K_{cut\ off}$ (cm/s)	1×10^{-8}, 1×10^{-7}, 1×10^{-6}
Number of analysis	27

Table 2-f. The variables considered in connection system 6

Variable	System 5
l/L	1/9, 2/9, 3/9, 4/9, 5/9, 6/9, 7/9, 8/9, 1
$K_{fill\ material}$ (cm/s)	5×10^{-9}, 5×10^{-8}, 5×10^{-7}, 5×10^{-6}
$K_{cut\ off}$ (cm/s)	1×10^{-8}, 1×10^{-7}, 1×10^{-6}
Number of analysis	108

EVALUATION OF THE RESULTS

In order to investigate the effect of each variable on the total flow and the maximum hydraulic gradient, the other variables were assumed to be constant. The total flow decreases with reduction of cut off wall permeability. However, the maximum hydraulic gradient remains nearly constant in all connection systems.

<u>Connection system 1</u>

The variables are the amount of cut off wall penetration into the core and the cut off wall width.

<u>Cut off wall penetration into the core:</u> The cut off wall penetration into the core decreases the total flow when the permeability of the cut off wall is less than the core. This is shown in Fig. 4. However, the total flow increases with cut off wall penetration when it has a more permeability than the core.

<u>Cut off wall width:</u> The total flow decreases with increase of cut off wall width and the maximum hydraulic gradient remains nearly constant.

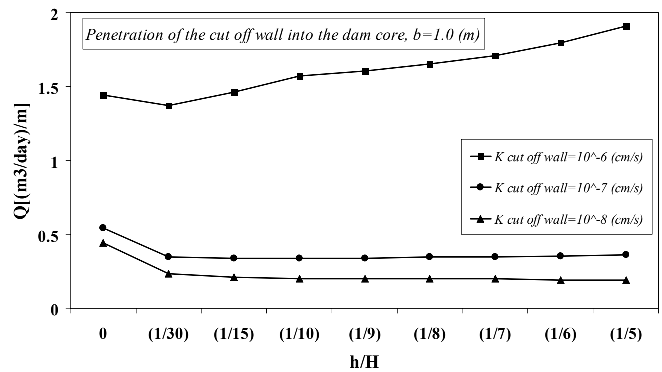


Fig. 4. Effect of cut off wall permeability on the flow in connection No. 1

<u>Connection system 2</u>

The variables are the slab location and the length or thickness of the concrete slab.

<u>Slab location:</u> The concrete slab can be located in the core, in the foundation or between the core and foundation. The results of the analysis show that the slab location has no effect on the flow and the maximum hydraulic gradient in connection zone.

<u>Slab length:</u> The total flow increases with increase in slab length. This is more evident when the slab has a more permeability than the core. This is shown in Fig. 5. The maximum hydraulic gradient decreases with increase in slab length.

<u>Slab thickness:</u> Slab thickness has little effect on the hydraulic gradient. However, the total flow decreases with increase in slab thickness. This is also shown in Fig. 5.

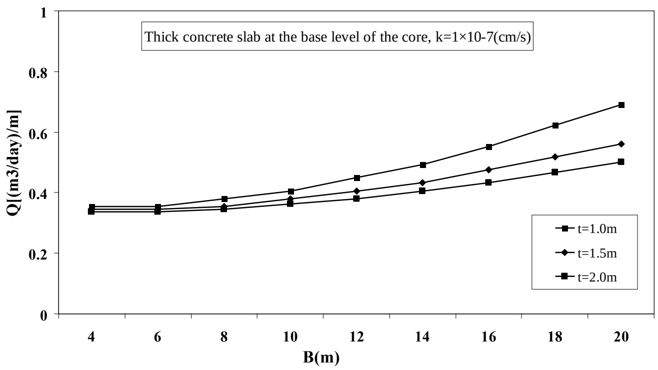


Fig. 5. Effect of slab length and thickness on the flow in connection No. 2

Connection system 3

The variables are the cut of wall penetration into the core, the slab location and the slab length.

Cut off wall penetration into the core**:** The total flow decreases with increase of the cut off penetration into the core. This is shown in Fig. 6.

Slab location: The results of the analysis show that the slab location has no effect on the flow and maximum hydraulic gradient in connection zone.

Slab length: The slab length has no effect on total flow. However, the maximum hydraulic gradient decreases with increase of the slab length.

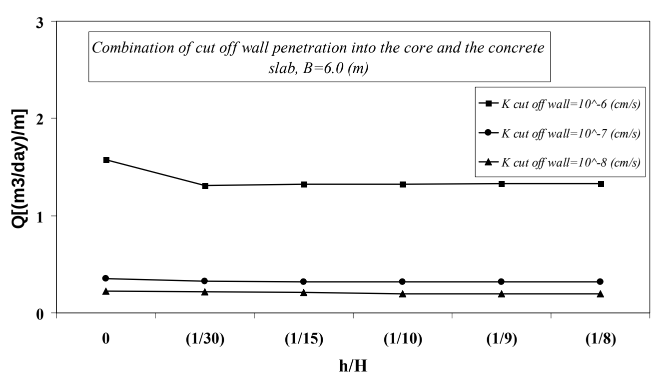


Fig. 6. Effect of cut off wall permeability on the flow in connection No. 3

Connection system 4

The variables are the grouted zone permeability. Also the length and depth of the grouted zone are among the other variables.

Permeability of the grouted zone: The total flow and the maximum hydraulic gradient decreases with reduction of the grouted zone permeability. This is shown in Fig. 7.

Grouted zone depth: The total flow and the maximum hydraulic gradient reduce with increase in grouted zone depth. The reduction rate is more as the cut off wall permeability increases.

Grouted zone length: The total flow and the maximum hydraulic gradient reduce with increase in grouted zone length. The reduction rate is more as the cut off wall permeability increases.

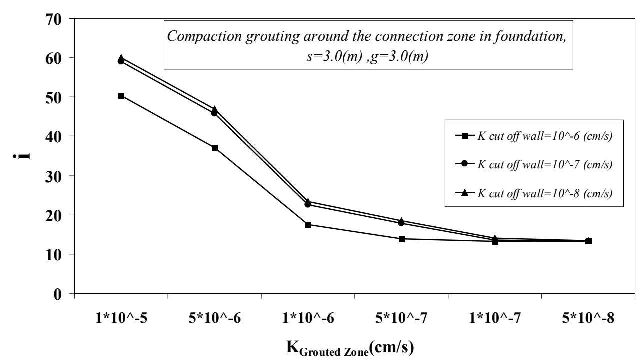


Fig. 7. Effect of grouted zone permeability on the maximum hydraulic gradient in the connection No. 4

Connection system 5

The variables are the permeability of the clayey soil under the cap and the cap angle.

Permeability of clayey soil under the cap: The reduction of permeability of clayey soil under the cap decreases the total flow and increases the maximum hydraulic gradient in connection zone.

Cap angle: The total flow increases with increase in cap angle. The analysis results are shown in Fig. 8. The same increase in the maximum hydraulic gradient can be seen when the permeability of the clayey soil increases.

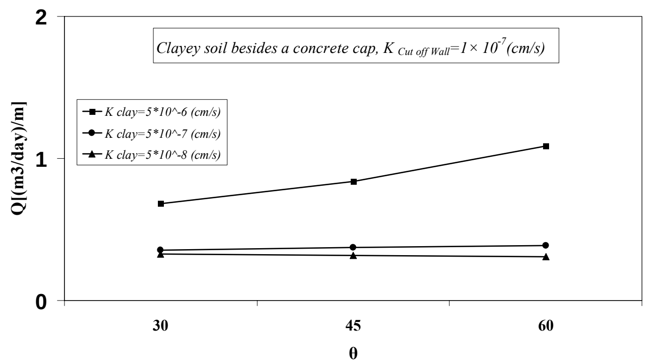


Fig. 8. Effect of θ angle on the flow in connection No. 5

Connection system 6

The variables are the filling material permeability and the trench depth.

Filling material Permeability: The total flow and maximum hydraulic gradient decrease with reduction of the filling material permeability. This is shown in Fig. 9.

Trench depth: The total flow and the maximum hydraulic gradient reduce with increase in trench depth. The reduction rate is more for filling material with lower permeability.

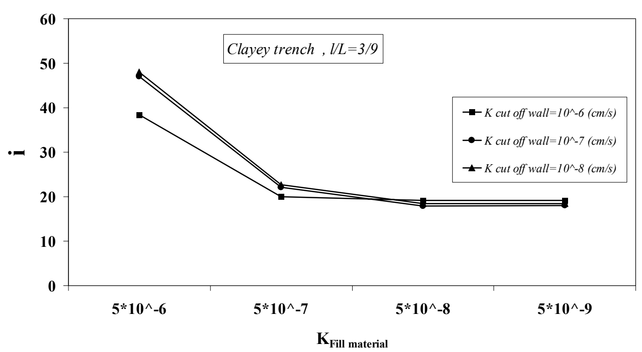


Fig. 9. Effect of filling material permeability on the maximum hydraulic gradient in connection No. 6

COMPARISON OF DIFFERENT CONNECTION SYSTEMS

The comparison of different connection systems performed in two stages. In the first stage, the maximum hydraulic gradients were compared in constant total flow. After that the total flow discharges were compared in constant maximum hydraulic gradient in the second stage. The state in which the cut off wall is connected to the core without any connection system is considered as the basic case for the comparison. The total flow discharge and the maximum hydraulic gradient of different connection systems are compared with this case.

Comparison of the maximum hydraulic gradients in constant total flow discharge

The comparison of the maximum hydraulic gradients for three different constant flow discharge values is shown in Tables 3 to 5. As indicated in these tables, the connection system (5) has a little effect in reduction of the maximum hydraulic gradient. The most effective connection systems are the first, second and third ones. However, the effect of the connection systems (1), (2), (3), (4) and (6) would be the same with reduction of cut off wall permeability.

Comparison of the total flow discharge in constant maximum hydraulic gradients

The connection system (5) is not considered due to the little effect on the maximum hydraulic gradient. The comparison of the total flow discharges of connection systems in the same maximum hydraulic gradient are shown in Tables 6 to 8. The results show that the connection systems (3), (4) and (6) are more effective in reduction of the flow discharge. However, the effect of different systems would be the same when the cut off wall permeability decreases.

CONCLUSIONS

1- The characteristics of connection system affect the flow discharge and the maximum hydraulic gradient in earth dams. The desired values may be obtained by changing the connection system specifications.
2- The thinner wall with lower permeability would be more effective in connection system (1). In this system the penetration ratio of 1/30 is the most effective one.
3- The concrete cap reduces the flow discharge. However, the cap dimension and its location have less effects. The most affective parameter on the flow discharge is the cut off wall permeability. Also the increase in cap length reduces the maximum hydraulic gradient.
4- The increase of the grouted zone dimensions has little effect on the flow discharge. However, it increases the maximum hydraulic gradient.
5- The under cap clayey soil is effective in reduction of the total flow in system (5) when its permeability is less than the core. The increase in cap angle increases the flow discharge.
6- The increase in trench depth has little effect on flow discharge. However, it decreases the maximum hydraulic gradient.
7- Comparison of the maximum hydraulic gradients in constant flow discharge shows the little effect of connection system (5) on the maximum hydraulic gradient.
8- The reduction of the flow discharge with decrease in cut off wall permeability observed in all connection systems except

for system (5). It seems that this connection system is not suitable compared to the other ones.
9- The connection system (3) shows the most effective characteristics besides the suitability in its construction.

Table 3. Comparison of the maximum hydraulic gradients in constant flow discharge of 1.25m^3/m/day, K cut off = 1×10^{-6} cm/s

	No system	System (1)	System (2)	System (3)	System (4)	System (5)	System (6)
System characteristics	-	h/H=1/30	B=4m t=1m	B=4m t=1m h/H=1/30	s=2m g=2m $K_{grouted\ zone}$= 5×10^{-6} cm/s	$\theta=30^{\circ}$ K_{clay}= 5×10^{-7} cm/s	l=1m $K_{fill\ material}$= 5×10^{-6} cm/s
Maximum hydraulic gradient	87.9	15.4	19.3	13.4	41.3	88.2	45.9
Reduction rate	-	+82.5	+78.0	+84.7	+53.0	-0.3	+47.8

Table 4. Comparison of the maximum hydraulic gradients in constant flow discharge of 0.35m^3/m/day, K cut off = 1×10^{-7} cm/s

	No system	System (1)	System (2)	System (3)	System (4)	System (5)	System (6)
System characteristics	-	h/H=1/30	B=4m t=1m	B=4m t=1m h/H=1/30	s=2m g=2m $K_{grouted\ zone}$= 1×10^{-6} cm/s	$\theta=30^{\circ}$ K_{clay}= 5×10^{-7} cm/s	l=1m $K_{fill\ material}$= 5×10^{-7} cm/s
Maximum hydraulic gradient	89.3	20.1	17.2	14.9	26.5	89.6	30.7
Reduction rate	-	+77.5	+80.7	+83.3	+70.3	-0.36	+65.6

Table 5. Comparison of the maximum hydraulic gradients in constant flow discharge of 0.25m^3/m/day, K cut off = 1×10^{-8} cm/s

	No system	System (1)	System (2)	System (3)	System (4)	System (5)	System (6)
System characteristics	-	h/H=1/30	B=4m t=1m	B=4m t=1m h/H=1/30	s=2m g=2m $K_{grouted\ zone}$= 1×10^{-6} cm/s	$\theta=30^{\circ}$ K_{clay}= 5×10^{-7} cm/s	l=1m $K_{fill\ material}$= 5×10^{-7} cm/s
Maximum hydraulic gradient	89.5	20.6	16.9	15.7	27.0	89.8	30.5
Reduction rate	-	+77.0	+81.1	+82.4	+69.8	-0.4	+65.9

Table 6. Comparison of the flow discharges in constant maximum hydraulic gradient of 15, K cut off = 1×10^{-6} cm/s

	No system	System (1)	System (2)	System (3)	System (4)	System (6)
System characteristics	-	h/H=1/30	B=6m t=1.5m	B=4m t=1m h/H=1/30	s=3m g=4m $K_{grouted\ zone}$= 1×10^{-6} cm/s	l=5m $K_{fill\ material}$=5×10^{-7} cm/s
Flow discharge m^3/ day/m	1.44	1.37	1.38	1.31	1.1	1.06
Reduction rate	-	+4.8	+4.1	+9	+23.5	+28.3

Table 7. Comparison of the flow discharges in constant maximum hydraulic gradient of 20, K cut off = 1×10^{-7} cm/s

	No system	System (1)	System (2)	System (3)	System (4)	System (6)
System characteristics	-	h/H=1/30	B=4m t=0.5m	B=4m t=1m h/H=1/30	s=2m g=2m $K_{grouted\ zone}= 5\times10^{-7}$ cm/s	l=4m $K_{fill\ material}= 5\times10^{-7}$ cm/s
Flow discharge m^3/ day/m	0.54	0.34	0.37	0.32	0.34	0.33
Reduction rate	-	+36.7	+31.2	+40.3	+36.7	+38.5

Table 8. Comparison of the flow discharges in constant hydraulic gradient of 20, K cut off = 1×10^{-8} cm/s

	No system	System (1)	System (2)	System (3)	System (4)	System (6)
System characteristics	-	h/H=1/30	B=4m t=0.5m	B=4m t=1m h/H=1/30	s=2m g=2m $K_{grouted\ zone}= 1\times10^{-7}$ cm/s	l=5m $K_{fill\ material}= 5\times10^{-7}$ cm/s
Flow discharge m^3/ day/m	0.43	0.23	0.23	0.21	0.23	0.23
Reduction rate	-	+45.7	+45.7	50.3	+45.7	+45.7

REFERENCES

ICOLD [1985]. *"Filling materials for watertight cut off walls*", Bulletin No. 51.

Karkheh Dam Section Engineers [1995]. "*Karkhe Dam Cutoff Wall Technical Specification"*, Mahab Ghodss Consulting Engineers, Tehran.

Karkheh Dam Section Engineers [1998]. "*Karkhe Project Technical report of Dam-Body and Foundation",* Mahab Ghodss Consulting Engineers, Tehran.

Shadravan, B., A.A. Mirghassemi and M. Pakzad [2004]. *"Karkhe storage dam cutoff wall analysis and design",* Proceedings of 5th International Conference on Case Histories in Geotechnical Engineering, New York, Ny, 13-17 April, Paper no.2.71

Shahbazian Ahari, R. [1999]. *"Static interaction of plastic concrete cut off wall in non homogeneous stratified dam foundation, Case study: Karkheh Storage dam"*, MSc. Thesis, Tehran University, Tehran.

Shahbazian Ahari, R., A.A. Mirghassemi and M. Pakzad [2000]. *"Investigation of the interaction between dam, foundation and the concrete cut off wall*", Proceedings of 4th Conference on Dam Engineering, Iran, pp. 452-459.