INTERNATIONAL SYMPOSIUM ON
DAMs IN A GLOBAL ENVIRONMENTAL CHALLENGES
Bali, Indonesia, June 1ST – 6TH, 2014

April 30th, 2014

Dear A. Akhtarpour , M. Damghani

We are pleased to inform you that your paper titled **3D Numerical Study of the Efficiency of the Grouting Curtain in an Embankment Dam** has been accepted as **Paper Poster**. Please register through the website of the http://www.icold2014bali.org not later than 10 May 2014 and prepare your Poster Paper to be displayed at the exhibition (Design template attached) also send your poster design to symposium@icold2014bali.org not later than 20 May 2014. Spelling and grammatical errors, as well as language usage problems, are not acceptable.

We would also like to get your information that you will attend the symposium and present your paper poster. Should there is any chance for your paper to be presented as oral presentation, we would inform you in due chance after having information from oral presenter.

Thank you for your kind cooperation.

Sincerely,

Bambang Hargono
Chair – ICOLD 2014 Symposium and Workshop Committee

Invitation from Chairman of Organizing Committee and President of INACOLD

Dear ICOLD Members,

On behalf of The Indonesian National Committee on Large Dams (INACOLD). I would like to extend our invitation to participate in the 82nd Annual Meeting of ICOLD. The event will take place in Bali on 2-6 June 2014 at Bali Nusa Dua Convention Center (BNDCC).

Along with the history of ICOLD, Indonesia has been recorded as member country of this world prestigious organization. For Indonesia, this is the second time we have been entrusted to host such an important event of ICOLD. The first one was in Jakarta in 1986. I believe that through this important event, we will be able to show you the whole set of our experience in implementing the country's development and management in large dams in particular and in the water resources development in general.

The selection of Bali as the venue of the meeting is not just because of its reputation as a tourist destination, but more than that, it has proven record of hosting various kinds of international events. It is also an opportunity to see boundless variety of unique sceneries as well as countless traditional and cultural heritages.

Our Social programs are designed to provide you with unique opportunities to taste and feel the best of Bali's hospitality and its unique culture, through various exciting and full-filled activities held before, during and after the event. To complement these, the distinct culturally rich province offers an extensive range of hotels, exquisite cuisines, fascinating sceneries, a genuinely friendly and charming people practicing an authentic ancient heritage culture and almost unlimited recreational and cultural options.

We trust that the time you spend with us in Bali will be most rewarding, which leads to many experience and friendships. We are looking forward to welcoming you to the 82nd Annual Meeting of ICOLD and hope that your participation will be productive as well as memorable.

Dr. M. Basuki Hadimuljono

Chairman of INACOLD

Preface

The International Symposium, with the main theme on DAMS IN GLOBAL ENVIRONMENTAL CHALLENGES, conducted in 4th June 2014, is one among the events in the 82nd Annual Meeting of the International Commission on Large Dams in Bali, Indonesia. It is a great honour to have all ICOLD delegates and dam experts, professional managers, as well as decision makers from the international dam community to participate in the international symposium. The objective of the symposium is to collect the knowledge of the latest development from the dam experts from various field of expertise to share with dam engineers in developed and developing countries, and to transfer especially to young dam engineers to ensure the dam engineering sustainability.

The topics in the international symposium are listed as follows:

1. Social and environmental aspects of dam,
2. Engineering issues in dam development,
3. Challenging in tailing dam project,
4. Dams and water quality management,
5. Catchment area management for sustainable dam development,
6. Challenges in dam safety policy and implementation,
7. Dam operation in connection with climate change.

We have received 532 papers from 53 countries related to the theme and the topics. These papers were evaluated by national reviewer as well as international reviewer, involving experts related to dam engineering and environment from various countries. The result is that 246 high quality papers, of which 146 papers are presented in oral session and 81 papers presented on poster session.

We also provide awards for the best paper and presenter among young engineers to encourage their further involvement in the dam engineering, development, and management. We hope, the presentations and discussions are fruitful, and further provide contribution to the future sustainable dam engineering.

Bambang Hargono

Chairman of the Symposium and Workshop Committee,
The 82nd Annual Meeting of ICOLD, 2014, Bali.

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Sub Theme 7: Dam operation in connection with climate change

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3D Numerical Study of the Efficiency of the Grouting Curtain in an Embankment Dam

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ABSTRACT:
"Siahoo" Dam is a central clay core embankment dam with a height of about 32 meters from alluvium foundation. The dam is under construction in the east of Iran (Khorasan Province).In the main design the alluvium foundation has been removed under the core and a grouting curtain with a depth of 32 meters from bedrock has been considered to prevent the foundation from excessive seepage. The bedrock consists of highly fractured and weathered volcanic rocks (Andesit) with high permeability that in some cases reach to more than 100 lugeon. Also some artesian regions were observed in the drilling and grouting stage in the construction phase. The normal Portland cement was initially used for grouting mixture but results showed that it has not a sufficient efficiency so the fine Portland cement (with a blain more than 7000) was used for this purpose. The existing of micro cracks in the volcanic rocks was suggested to be the main reason for this phenomenon. Finally after completion of the grouting curtain, some regions of the rock foundation in the controlling drills show more permeability than design criteria. In this research the efficiency of the grouting curtain was evaluated based on the 3D saturate/unsaturated numerical seepage analysis of the dam body and foundation. The numerical methods with the assumption of a continuum media can be used with an adequate accuracy for highly fractured rocks. Results show even in a case of high permeability in some regions of the grouting curtain, the grouting curtain has a good efficiency in control the flow from the dam foundation also gradients in the downstream are in a safe manner so the uncontrolled seepage and erosion in the foundation is not expected after the reservoir filling.

Keywords:* *Embankment dam, Grouting Curtain, 3D Numerical Seepage Analysis, Volcanic Rocks

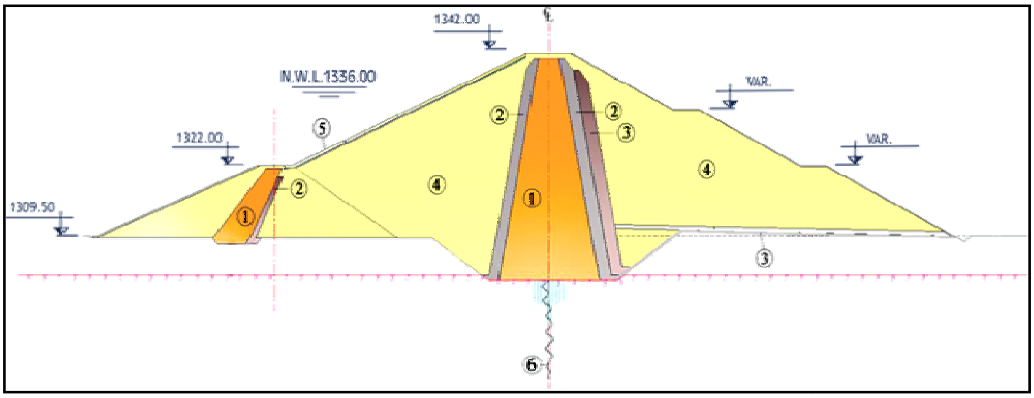
1. INTRODUCTION

The common method for providing the sealing of rock foundation in majority of dams is to use grouting curtain which according to the geological conditions of the dam position, design of the curtain and specifications of the slurry will be different. In some positions, the common methods of injection are with restrictions and are not the supplier of complete sealing. In this study, the efficiency of the grouting curtain of Siahoo dam has been studied in terms of seepage rate and gradients controls which are on the excessive fractured volcanic formations. In this dam, despite of using fine cement (blain over 5000), in some parts of the injection curtain, the possibility of achieving complete sealing (lugeon 5) was not provided. In this case, there will be a concern about the efficiency of the curtain in controlling the leakage and to prevent the erosion, which this study used the numerical method by using the advanced Seep3D software.

2. SIAHOO EARTH DAM

Siahoo dam is under construction by the aim of haltering some water frontiers in east of the country for the purpose of farming uses. Siahoo River is one of the frontier Iran's rivers which flow from north into the south and east in Doroh plain of south Khorasan Province.

Siahoo basin is over 3000 square kilometers. Siahoo reservoir dam has a height of 32.5 m from the river bed and about 39.5 m from rock foundation, a crest length of 352 m and the reservoir volume of 17 million cubic meters. The dam is a central clay core embankment dam. Typical cross section of the dam is shown in figure (1). The river bed alluvial is dense coarse-grained with a maximum depth of about 7 meters which is removed only under the dam core area.



1. Clay care 2. Sand Fillet 3. Drain 4. Sand and Grave shell 5. Rip-Rup 6. Grouting Curtain

Figure 1. Typical Cross Section of the Siahoo Dam

3. MODELING AND NUMERICAL ANALYSIS

In order to model the seepage in the body and foundation of the Siahoo Birjand dam, we have used a three dimensional finite element computer program. This analysis has done in steady seepage and the different parts of dam sealing system including core, grouting curtain, upper and lower rock foundation in analysis has been taken into account. Due to the extremely high permeability of alluvial foundation and its removal under core area, we have relinquished from the modeling. Also, because of the dam shells consist of course grained soils, they have no effect on leakage rate and they have eliminated from the model. It should be noted that for the excessive fractured rocks which have the same behavior as the soils in terms of hydraulic behavior, the numerical methods assuming the continuous media can be used with reasonable accuracy.

3.1. Geometry of Numerical Model

You can see the cross-section of curtain sealing and dam axis in figure (2), and the geometry of three-dimensional model in figure 3. Also in figure (4), you can see the way elements are generated.

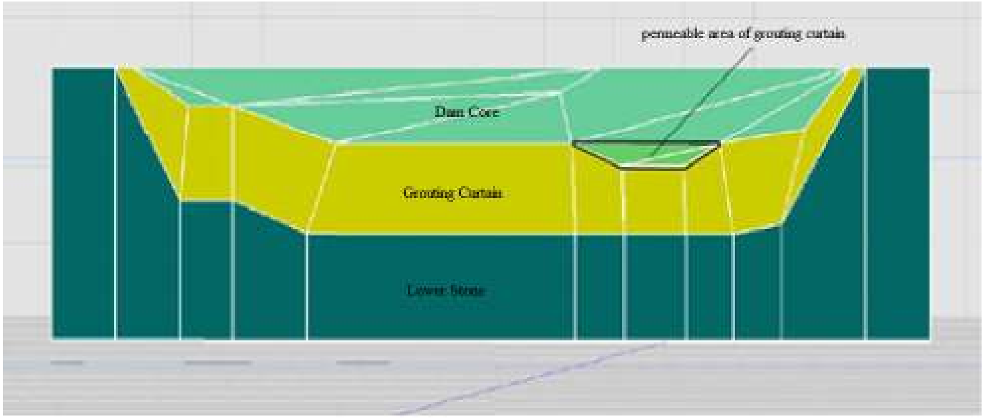
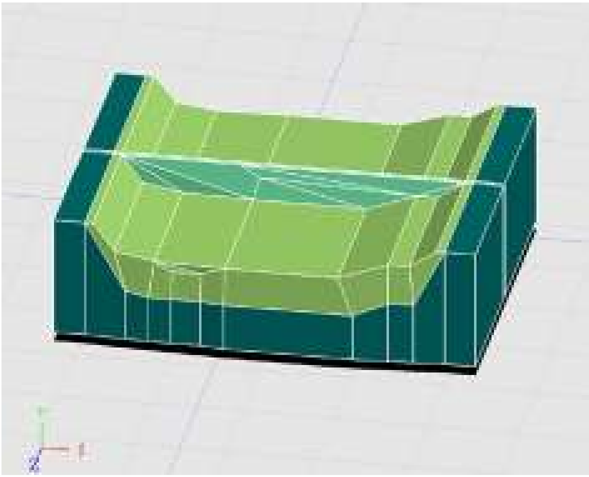


Figure 2. Longitudinal Cross Section of the dam and Grouting Curtain



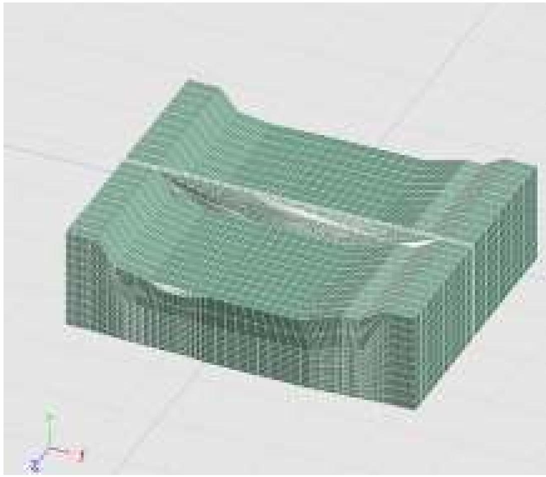


Figure 3. Geometry of the 3D Model **Figure 4.** Mesh Generation of the Finite Element Model

3.2. Hydraulic Parameters of the Sealing System Components

- Dam core

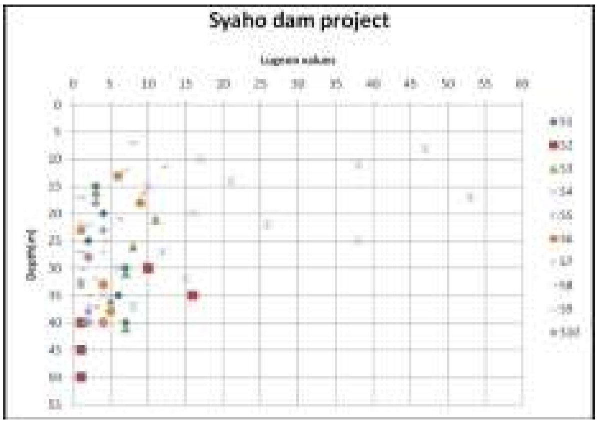
Based on 6 permeability tests in the design stage and in order to ensure, the permeability is considered 10^{-6} centimeters per second in the numerical analysis

3.2.1. Geology and permeability of bedrock

Based on the geological studies, the left abutment is igneous clastics (pyroclastic) volcanic andesite stones and the masses of the middle part of dam are agglomerate and tracky andesite. On the right side, the porous basaltic lavas agglomerate and above it, conglomerate has been observed. According to this fact that Siahoo dam is located in a position with highly tectonic volcanic formations, its sealing has been the particular interest of the design consultant from the beginning. Accordingly, before the execution of the grouting curtain and after that, exploratory and controlled boreholes were drilled and the water injection tests were done, which based on that, the results of that design and the execution of dam curtain injections has been evaluated and in case of need, additional injections have been done too. In figure (5), you can see the water seepage test results in the drilled boreholes in the studies stage. Statistical analysis of the obtained lugeon values from first phase exploratory boreholes shows that 60% of permeability is less than 5 lugeon units. As presented in figure (5), the mass rock is permeable about 35 meters from the surface of bed rock mass and 40 meters from the earth surface. Accordingly, the proposed depth for the water dam curtain is 40 meters.

Ex series boreholes have been drilled before the execution of the injection curtain, and the water pressure tests in exploratory boreholes have been done from EX5 to EX12. The results of these tests have been used in burying the depth of water dam curtain. In figure (6), you can see the lugeon test results in EX series boreholes.

As you can see, in some of the boreholes in upper part of the rock foundation, the values are about 100 lugeon, which shows the significant water permeability capability of the upper rock, and it also shows a significant difference to the early study results. According to these results, the bedrock in numerical analysis has been divided in to two parts.



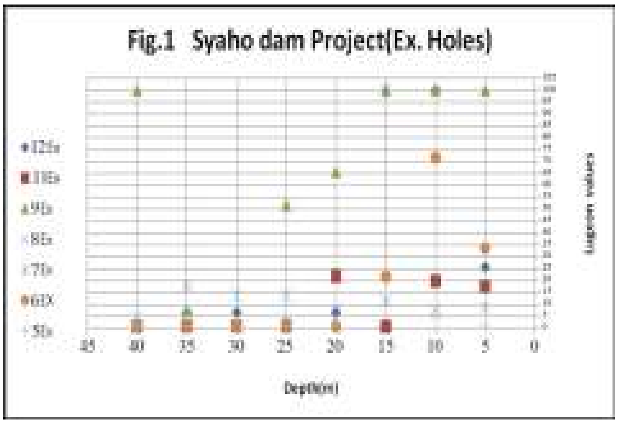


Figure 5. Permeability (Lugeon) of the bedrock based on the permeability tests in design stage

Figure 6. Lugeon values in EX-Series of boreholes

The upper zone which extends to a depth of 40 meters and the dam injection curtain are situated in this area, and the lower zone which is located under the injection curtain and has the lower permeability than the upper zone. The considered lugeon values for the upper zone are between 15 to maximum 100 lugeon, and the lower zone is 3 to 15 lugeon.

3.2.2. Permeability of the grouting curtain

In figure (7), you can see the longitudinal cross-section of water dam curtain and the injected boreholes up to January of 2010.

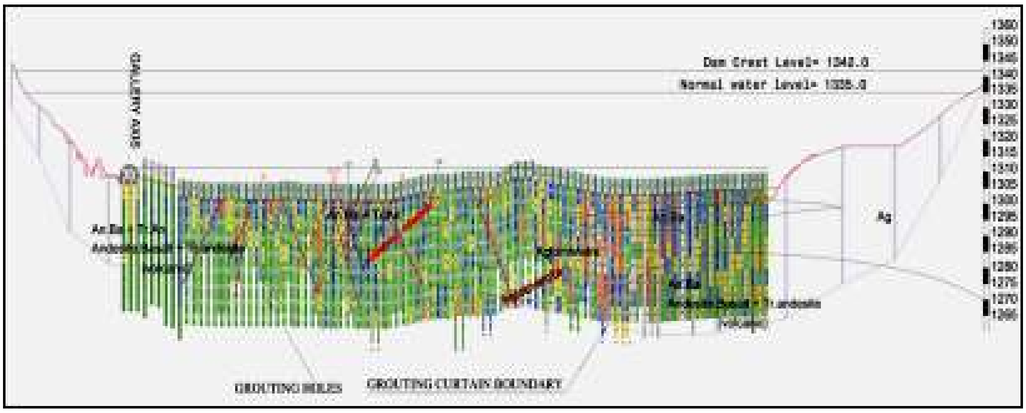


Figure 7. Longitudinal Cross section of the curtain and injected boreholes until Jan. 2010

After the initial execution of water dam curtain injections, some controlled boreholes of Co series have been drilled and lugeon test has done on it. In figure (8), you can see the results of these tests in the mentioned boreholes. As you can see, despite the injection of one row from assisting injected boreholes at upper of the sealing curtain, there is a significant permeability in the upper 10 meters of mass rock in the area situated in the bed and near the left.

So, in order to check the existence of this permeable area in seepage amount of dam foundation, for the numerical analysis, the mentioned area has been taken into account.

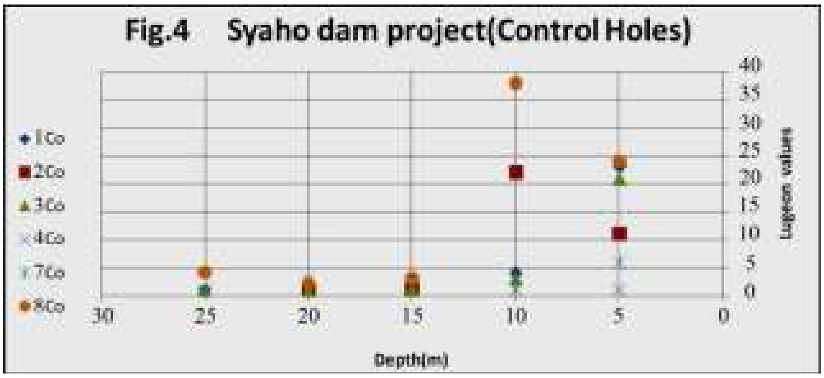


Figure 8. Lugeon Tests results in Co. Series of boreholes

4. ANALYSIS RESULTS

4.1. Amount of Leakage

Figure (9) shows the same potential curves in the three dimensional model. The reservoir water level is considered more equal than the water level normal, and in the lower area, the exit flow area is automatically determined by the program and by considering the permeability of core and supports in the unsaturated zone. As we have mentioned, sensitivity analyses have been done in order to examine the role of permeability parameters of different areas in this model including upper and lower rocks, and the permeable area of sealing curtain on the leakage amounts of the dam.

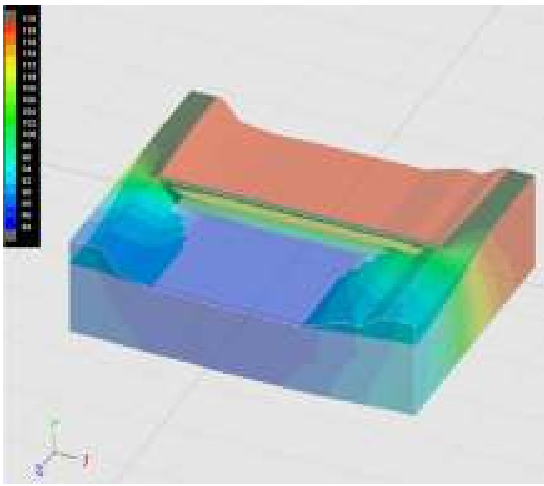


Figure 9. Potential Curves in the 3D finite element seepage analysis

In the first series of analyses, the lugeon number of different parts is as table 1.

Table 1. Assumed permeability of sealing system parts (Lugeon)

Lower rock foundation	Upper rock foundation	Sealing curtain	Left permeable area in sealing curtain
9	15	6	10~25

Given that some parts of the leakage discharge from the foundation are revealed in downstream rock abutments and are measurable by the establishment of a collection system inside the dam shell, this amount of discharge has been presented separately. As presented in figure (10), you can see the separate amount of total leakage and also the amount of visible leakage in lower rock abutments. In order to study the influence of the lugeon number in permeable area of sealing curtain to leakage amount, different values for permeability have been considered.

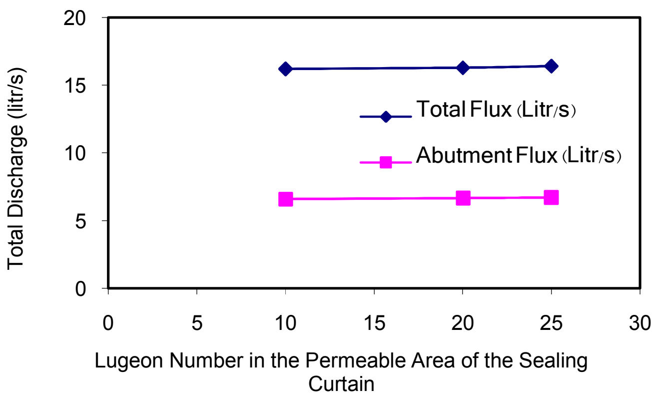


Figure 10. Amount of Leakage from the dam body and foundation as a function of the permeability of the permeable area of sealing curtain

There will be very little impact on the total amount of leakage by permeability reduction of left area from 25 to 10 lugeon. In order to investigate the influence of the average lugeon number of the average upper area of rock foundation on the leakage amount, the second series of analyses have been done by the consideration of the average lugeon number of upper area of the foundation equal to 50 lugeon, and the results show as the figures of 11 and 12. In figure 12, the average of lugeon number in lower stone is equal 9 lugeon, and in the figure 13, the average lugeon of lower area of the stone is equal to 3 lugeon.

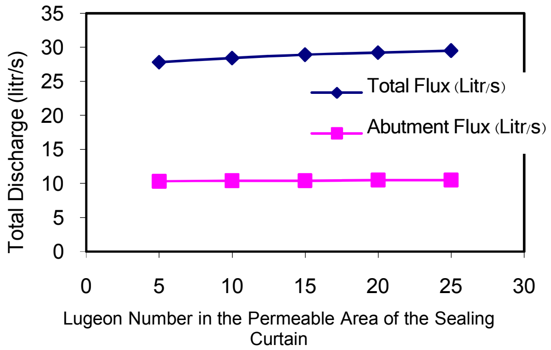


Figure 11. Leakage as a function of the permeability of the permeable area of sealing curtain (considering 9 lugeon for lower stone)

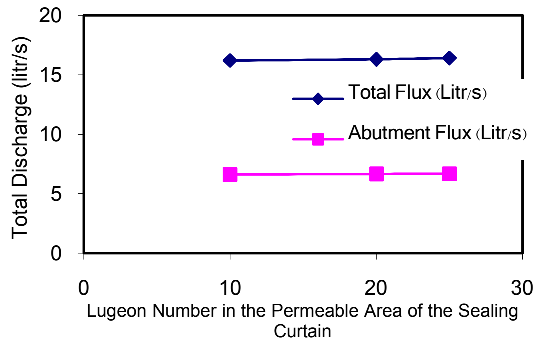


Figure 12. Leakage as a function of the permeability of the permeable area of sealing curtain (considering 3 lugeon for lower stone)

As can be seen, the permeability amount of the lower part of rock foundation has significant influence on the total values, so that the leakage rate based on the permeability of the lower rock is variable between 33.2 to 27.8 liters per second. In this case, the ok leakage rate from downstream rock abutments is variable between 10.3 to 12.2 liters per second.

In another analysis, in order to examine the influence of lugeon number in lower bedrock area on leakage amount of dam foundation, a series of analysis with the similar circumstances to previous and with different proposed values of permeability for lower bedrock has been done, then in figure (13), the results have been showed.

As we can see, the lower area permeability has a significant impact on the leakage amount, so that as the lugeon number increases from 3 to 15 lugeon, the total dispatch leakage lugeon increases from 29.5 to 36.5. However, the results of injection tests of lugeon in this area show that the lugeon number is less than 5.

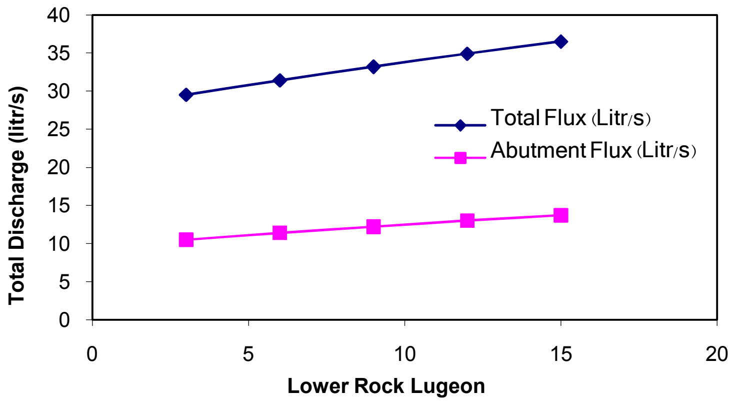


Figure 13. Amount of Leakage as a function of the permeability of the lower stone

4.2. Gradients Review

In order to examine the impact of permeable area in the grouting curtain on gradients amounts in rock foundation, the amount of exit vertical gradient from the rock foundation in the downstream of the core have been investigated in two cases. In the first case, the permeability of the upper part of rock foundation is assumed as equal to 50 lugeon, lower part is as equal to 9 lugeon and the grouting curtain is uniformly as equal to 6 lugeon. Analyses in second case are similar to previous case but the lugeon number of permeable area of the curtain is equal to 25.

In figure (14), you can see the vertical exit of gradient from the rock in downstream of the core and near the permeable area of the grouting curtain in two cases. As we have mentioned at the start of this paper, width of the permeable area has been assumed as equal to 70 meters and the horizontal axis in the diagram shows this width.

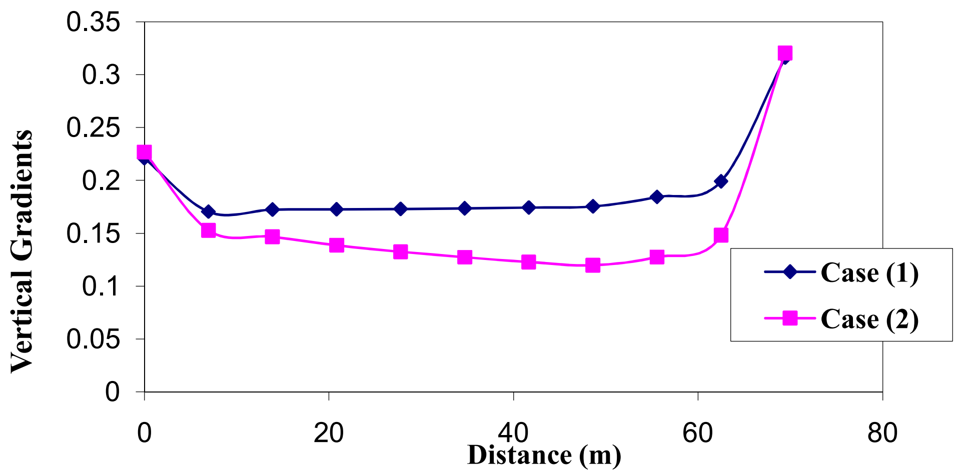


Figure 14. Hydraulic Gradients in the rock foundation (downstream area of the clay core)

As we have expected, the diagram values at the both ends are similar, because near this outer area of the region, the situation in both cases of analysis are similar. In the mid-range of downstream permeable curtain area, the gradients are almost uniform and a considerable remark is that in the second case, the gradients values have been decreased. According to the Darcy's law, increasing permeability in one restricted area, although causes the increasing in velocities, but not necessarily cause the increasing in the gradients, but also causes the reduction of the gradients.

If the bedrock is assumed same as the coarse grained soil, its critical hydraulic gradient can be calculated about 1.3, and so, the safety factor in contrast to erosion in the worst area (adjacent to both ends) is more than 4 for the both states, and therefore with this criterion, there is sufficient ensure margin in contrast to erosion.

5. CONCLUTIONS

The results of this analysis can be summarized as follow:

1- Based on to the water permeability test results in boreholes of the study stage, the assumption of the average permeability of the upper part of the rock foundation is equal to 15 lugeon and the leakage amount from the body and foundation in this case is maximum 16.4 liter per second. From this leakage amount, about its 6.7 liter per second will appear in the downstream rock abutments.

2- Based on the results of the water injection tests before the start of the grouting activities (EX series), the assumption of the average permeability of the stone in the upper part of the rock foundation mass is equal to 50 lugeon, and the leakage amount from the body and foundation is maximum 32.2 liter per second. From this leakage amount, about its 12.2 liter per second will appear in the downstream rock abutments.

3- The sensivity of the leakage amount to permeable grouting curtain area which is located in the left side of the grouting curtain - is small, so that increasing the permeability of this area from 5 lugeon to 25 lugeon causes the increasing of the discharge leakage about only 6 percent. So, more injections in this area that is associated with the increasing costs of the dam construction, seems unnecessary.

4- Performing a drainage system near the downstream abutments of the dam has been proposed, so that we can measure separately the leakage amount of abutments from the bed leakages.

5- Increasing permeability of the permeable area of the grouting curtain in the left side, the vertical gradients in the downstream of the core and in the bedrock show decreasing, and so there is no worry about the corrosion.

6- The exit gradients from the rock foundation which have the safety factor of 4 against erosion are at the safe side, and furthermore, in detailed design of the dam body, there is a downstream fine filter on the bedrock to prevent the internal erosion and it can be assumed as the double insurance agent against the erosion in this area.

ACKNOWLEDGEMENT
Special thanks to Mr. Bahrami Samani and technical office of Iran's water resource management, particularly Mr. Shokrollahi and Dr. Javaheri.

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