Application of Double Continuum Porosity Equivalent Method to Investigate the Karst Problem of Salman Farsi Dam in Iran

M.H. Fattahi[۱], *N. Talebbeydokhti*[۲], *A. Shamsai*[۳]
[۱] *Marvdasht Islamic Azad University,* [۲] *Shiraz University,* [۳] *Sharif University of Technology*

Abstract:

Karst is a dry landscape situated on soluble carbonate rocks. Limestones and dolomites with underground flow of water. Although karst terrains of the world make a relatively minor percentage around ۱۰% of the earth surface but they present the most risk producing conditions for a fulfilling in project objectives among the other geological formations.

In this research we are after to figure out the karst main problem, seepage, in dams and reservoirs and study this phenomenon numerically. The complexity of the karst system problems in Salman Farsi dam site is so serious that a variety of remedial measures has been presented. Among those five main suggestions are chosen to be modeled.

Choosing the best numerical method to analyze the karst problem needs a complete study of all possible ways. After a full introduction on different modeling methods we have a full investigation about Salman Farsi dam geology and hydrogeology conditions. Complicated karst caves and caverns systems and the dam right abutment fractured formation had encountered a lot of problems for the dam water proofing. Finding the best water proofing method was an aim.

The numerical method chose for this research is Double continuum Porosity Equivalent (DCPE). Our most important objective is to model the seepage flow from Salman Farsi karstic formation. The visual MODFLOW program has been used to grid the area and the dam characteristics inputting data. The different suggested technical methods for water proofing are modeled with DCPE and the results are compared, analyzed and tabled. The DCPE method has three kinds of output which are the base of Judgment. "Constant head OUT", "Other porosity" and "Total IN_OUT" are the program results which the last one has been chosen as the criteria of choosing the best seepage control method presented according to the minimum amount of seepage downstream. The procedure, flowchart, Analysis, results and conclusion and suggestions are presented in this paper.

Introduction:

Karstifed limestone terrains are very prolific sources of ground water. Their flow characteristics have been studied in much detail at numerous locations. The complexity of the flow system is primarily determined by the degree of certification.

The complexity of karst as a geological phenomenon is a difficult in studying as its engineering karst problems. Karst with an estimated ۱۰% over covering of the earth surface (Altug S. ۱۹۷٦) is a vast case of research. Considering the day increasing need of man to water sources and the optimal use of karst researches have promoted recently.

The water leakage from dams and reservoirs due to the karst effects and its features such as fractures and holes and sinkholes and ponors occurs mostly after the priming (Briznik M. ۱۹۸۲). In some dams this water loss exceeds to even ۳۰m^{۳}/sec. (Bozovic A., ۱۹۸۱). This amount of water is like a question mark in front of all the dams' objectives. Its clear that finding, analyzing the problems and of course the remedies of the case is so important.

Although the karst terrains consist only a small percentage of the earth surface (Bergado T.D.۱۹۸٤), but from the development and controlling the water sources and also running the hydro projects are of the most complex and risky ones in the world and among all the other geological formations. The importance of karst studying is considered from two points of view. First is the better quality of these water sources and their less pollution and also their considerable storage volume. Second is investigating the karst problems especially in regard to the hydro projects. The karst subjects would be more important to us the time we know in a dry country such as Iran and almost poor in rainfalls, there are a lot of karst formations full of water witch can provide our needs.

The objective of this research is to study salman Farsi dam karst problems. This dam located in Iran has encountered a lot of problems. The complexity of karst systems in site area is of that range which has caused different theory about the remedial works. Studying and analyze these theories and finding the best treatment is one objective in the case. Our most important aim of this research is studying the various numerical models used to analyze a karst media. As you know the complexity of karst area and it′s principle differences in flow, storage and governing equation with a non karstic area and the troubles of the Darcy equation in modeling have made the case so complicated. We have studied the different karst numerical models and suggested the best one according to the advantages and disadvantages of each. Among all the researched models, double continuum porosity equivalent (DCPE) is the most modern and complete one. Using this model and the visual MODFlOW support, the dam site is modeled and the seepage results are presented through program runs. All the results are compared and presented at the end.

Literature Review:

Considering the karst complicacy, studying and research to solve it′s problems is a great need nowadays. The greatest Jump in karst research for sure has been the numerical movement from the last years of the twentieth century and up to this century. The first sparks have been lightened by Sauter, Teutsch and the others. Creating numerous models to analyze the ground water flow in karst regions shows the importance of the case for the scientists. Different researchers, scientists and karstmen throughout the world such as, Ford, Breznik, Beck, white, sweed, Herake, Duinlan, Jennings, Wilson, Milanovic, Vlahovic, Stringfield, parizan and many others have preformed a vast attempt to know karst, it′s hydrology and hydrogeology and its different problems and of course the remedies in the recent ۳۰ years. But karst research is a nonfullfillment case of studying.

Karst numerical models:

Two fundamental approaches to modeling karst water resource systems have been considered. The black box model and distributed model.

Black Box Model:

In this model, the input data are given to a system and as a result of the system function the output data are obtained. This system doesn't encompass a physical source and just its results are considered. As a result of the scarcity of spatial data, the heterogeneity of the aquifer parameters and because of its relative simplicity a black box approach has been frequently used to study the simulation of karst aquifers. The used methods in these models are various. Like the recession analysis (Atkinson, ۱۹۷۷)[۱], Transfer/kernel function (Dreiss, ۱۹۷۹)[۱], Mixing cell model (Simpson, ۱۹۸۸)[۱] and Simple Regression Analysis (Zaltsberg,۱۹۸۹)[۱] but according to what described about these models, as dealing with a nonphysical nature and condition, they can not be used to predict the aquifers internal formation, in other words, they lack the predictive power.

Distributed Parameter Models:

The inadequacies of the black box models become apparent when one attempts to model spatially variable output phenomena, such as characteristic water level fluctuations, that have a definite physical basis. Frequently, geological information that could explain observed differences, which in many cases is of a spatial nature has to be ignored in such models. Moreover, they fail to consider the different processes that determine flow and transport in a karst aquifer, i.e., the mechanism of ground water recharge, the influence of the unsaturated zone and the phenomena in the aquifer itself. Furthermore, each of these factors in turn has a different influence on fast and slow flow components.

A viable alternative is the distributed parameter modeling approach. Three major methods have been used to describe the flow and transport through fractured porous media, (۱) the equivalent porous medium, (۲) the discrete fracture and (۳) the double porosity or double continuum approach.

Equivalent Porous Medium:

When the fractures are narrow, evenly distributed, and if there is a high degree of connectivity, an equivalent porous medium model (EPM) can be applied (Pankow et al., ۱۹۸۶). A recent development for these kinds of model has been described by Newman (۱۹۸۷). Sauter (۱۹۹۲) simulated the flow in the fractured porous rocks with an equivalent porous medium model, integrating the permeability as a stochastic variable. Aquifers termed "Deep Continuum Flow Carbonate Aquifers" by Thrailkill

(۱۹۸٦) seem to fall into this category. Most of the present karst aquifer models have been based on the assumptions of the EPM.

Discrete Fracture Models:

The second approach, the discrete fracture model usually implies that the effect of the matrix is neglected. In its simplest form, flow is simulated by considering it as flow between two parallel plates and it requires some detailed information of fracture apertures, fracture length, density, orientation and connectivity .

Especially as it is very difficult, if not often impossible to obtain the required information at the relevant scale, the fracture networks are statistically simulated (Long et al., ۱۹۸٥). Kraemer and Haitjema (۱۹۸۹) theoretically studied the effects of large fracture zones and statistically generated fracture networks for regional aquifer flow. Although the theory for joint controlled flow is outlined in many textbooks and publications (White, ۱۹۸۹, Ford and Williams, ۱۹۸۹) and although the laws and parameters governing turbulent open channel flow and pipe-flow were described in detail, to the authors knowledge, these principles have not been applied to real aquifer situations, except by Atkinson (۱۹۷۷) and Thrailkill (۱۹۹۱).

Fracture Flow Model Concepts:

A variety of modeling concepts have been proposed for the simulation of the hydraulic behavior of fractured rocks. The concepts are based on either a discrete or continuous representation of the fracture flow system, together with equation describing the exchange between the fractures and the rock matrix.

In the discrete fracture approach, the location and the geometry of the fractures are assumed to be either exactly known, or at least describable through a statistical model. Several analytical and numerical studies have been conducted employing the discrete fracture approach, including early laboratory and theoretical works by Wattle & Louis (۱۹٦۸), Gringarten (۱۹۷۱), Grisak & Pickens (۱۹۸۰), and. Most of these studies dealt with crystalline rocks for some other low-permeability system. It was therefore in general assumed that groundwater flow occurs in the fracture system only, the adjective flow within the porous matrix being negligible.

The major drawback of the discrete fracture approach is the necessity to describe the geometry and hydraulic properties of all individual fractures within the flow domain. For most regional aquifer systems this is not feasible in practice. So far, only a few very intensively investigated radioactive waste disposal sites of very limited areal extent have been characterized using the discrete fracture modeling approach. Bearing in mind that fracture permeability is proportional to the square of the fracture width, no reliable regional rock permeability assessment is to be expected using indirect underground investigation techniques available today (e.g., geophysics). In the continuum approach, it is assumed that the fractured medium can be described by one or more porosity equivalents. Often a double-porosity approach is employed, one porosity representing the low-permeability porous or fractured rock matrix, the other porosity representing the higher permeability fracture system.

The double-porosity model concept was introduced by Barenblatt et al. (۱۹٦۰). It was extensively used and further developed in oil industry studies including work by warren & Root (۱۹٦۳), Kazemi (۱۹٦۹), Streltsova-Adams (۱۹۷۸), and van Golf-Raacht (۱۹۸۲). At first, the magnitude of the cross-flow between the matrix and the fracture system was assumed to be directly proportional to the lumped pressure difference between the two systems.

Double porosity theory

The modeling of flow and transport in fractured rocks could benefit greatly from studies carried out by petroleum engineers in the field of reservoir engineering and from the research efforts in the search for safe repositories for radioactive wastes. The preferred approach in these areas of research has been the double porosity approach (Barenblatt et al., ۱۹٦۰; warren and Root; ۱۹٦۳; Duguid and Lee, ۱۹۷۷). The fractured medium and the porous matrix blocks are modeled as to separate over lapping continua, each with its own flow equation. The exchange of flow is controlled by the local difference in potentials. The coupling of the two media is handled with a source/sink term in each equation. Details and the development of the double porosity approach are described by strelsova (۱۹۸۸)and Teutsch (۱۹۹۳), Narasimham (۱۹۸۸), developed this concept further into multiple porosity systems and called the model MINC (multiple interacting continua). In double porosity theory, the porous Hetrogen media is assumed as two separate systems that are overlapped.

۱. The fractured media with a low-permeability with its hydraulic characteristics are regarded to the primary porosity
۲. The system that includes the conduits with high permeability is the secondary porosity which its hydraulic characteristics are controlled through the thermal stresses and tectonic events. Considering the conduits more openings, permeability and the flow velocity in this system is much more than the fractured system. As in karst media a doual nature exists and for each of them a differential equation is available, Monech et al. (۱۹۸٤) presented a REV (Representative Element Volume) for each of them. Applied to a karst aquifer, the terminology of the double porosity or double continuum approach requires some further clarification: The terms fractures and conduits are used interchangeable for the fast transit system, and matrix and fissures are used to describe the slowly draining part of the aquifers system. Although generally used in the literature, it is preferred to use the term "fissured system" as opposed to "diffuse system", because "fissured system" describes the actual permeable pore space of the slow system, corresponding to the term "conduit system". The term "fractures" is used synonymously for conduits in order to reflect the duality fracture/matrix of the double porosity /continuum approach. The same terms apply to the unsaturated zone, in particular to the epikarst. In double porosity theory, these are two hydraulic conductivities (k) and two storage coefficients (s) assumed for each point. One "k" is referred to the matrix media and the other one to the conduits. And a same formation exists about term “s”. The relationship between these two can be expressed by this equation in which Q_α is the discharge between the systems.

$$Q_\alpha = -\alpha\,(h^a - b^b)$$

The above equation is taken under the pseudo-steady state and straight relation between the two systems water head. In which, α is the specific conversion factor (۱/(T)) and (h^a-b^b) is the water head offset between two systems. There are differential equations for each media in three dimensions as below:

$$\frac{\partial}{\partial x}\left[K_{xx}^{a}\frac{\partial h^{a}}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}^{a}\frac{\partial h^{a}}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}^{a}\frac{\partial h^{a}}{\partial z}\right]=S^{a}\frac{\partial h^{a}}{\partial t}+\alpha_{0}\left(h^{a}-h^{b}\right)$$

$$\frac{\partial}{\partial x}\left[K_{xx}^{b}\frac{\partial h^{b}}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_{yy}^{b}\frac{\partial h^{b}}{\partial y}\right]+\frac{\partial}{\partial z}\left[K_{zz}^{b}\frac{\partial h^{b}}{\partial z}\right]=S^{b}\frac{\partial h^{b}}{\partial t}+\alpha_{0}\left(h^{a}-h^{b}\right)$$

h: water head
K_{xx}, K_{yy}, K_{zz}: Hydraulic conductivity in ۳ directions
S: storage coefficient
α : Conversion factor between the two systems
S_s: specific storage coefficient
"a" stands for conduit and "b" for matrix.

The double porosity model is prepared in different version. For this research, we have tried the MOHRLOCK version which is the most complete and exact one.

Geological and Hydro geological Conditions

General Geological Conditions

The dam site is located in the northern flank of the Changal Anticline in the Asmari limestone formations. The core of the Changal anticline consists of the Paleocene/Oligocene Pabdeh Formation. Lithologically, this formation is a cherty, fossiliferous and conglomeratic limestone, passing into shale, interbedded with thinly bedded marly limestone. This formation is not prone to karstification. From the hydrogeological point of view, this formation is watertight and can be declared as a regional hydrogeological barrier.

Overlaying Lower Asmari Formations (Oligocene to Early Miocene) consist of regularly bedded limestone with and alternation of numbers of thin marly beds in the base. The upper subunits of Lower Asmari are prone to karstification. Hydro geologically, the base sequence (Subunit ۲٤) can be declared as generally watertight.

The Middle Asmari (dam foundation area) is composed of marly limestone, intensively karstified with vuggy porous crystalline nummulitic limestone. Large karst features are developed in this sequence.

The structural and hydrogeological homogeneity of the northern flank of the Changal Anticline is tectonically disturbed with a few rupture systems. Five of those systems were detected in the field, but most important are the J۱ and J۲ systems. The intensity of crushing along those systems and the aperture of openings varies from only a few centimeters to a few meters in wide mylonite zones. The subvertical dip favors the ground water circulation by gravity, provoking the karstification process. J-systems are frequently close to the gorge (dam site) area. Because of the presence of shaly and marly interbeddings in the anticline core those ruptures, when crossing the core, are compressed and impervious. Any water movement penetrating through these formations is not possible.

The characteristics of the bedding planes are different. Some of them are very compact without the possibility for water circulation by gravity. However, along many of the bedding planes discontinuities are developed. In some cases, especially in middle and Upper Asmari, interbeddings consist of thin clayey layers with a thickness of ۱cm to ۲۰cm.

General Aspects about Karst Features

General characteristics of investigated karst channel at the Salman Farsi dam site are:

- Karst channels are developed along the dominating fractures (interbedding J-۱ and J-۲). All channels and caverns are very poor with speleothems.
- The caverns and channels are very dry (permanent or temporary watercourse do not exist above the river elevation).
- Hot microclimate (air temperature in natural conditions ranges between ۳۰°C - ۳۵°C)

On the base of investigated and observed karst features the following groups of caverns are distinguished:

- Large caverns filled with piles of huge limestone blocks. In the lower sections of those caverns, the blocks are surrounded by clayey matrix. The bottom of a solid rock mass is mostly unknown.
- Caverns filled with well stratified, compressed and plastic clay are present at both sides. Some of them are almost fossilized. The volume of those caverns varies from a few cubic decimeters till a few hundreds of cubic meters. The clay color is different: gray, reddish, dark brown and beige.
- Karstic channels, mostly subhorizontal are blanketed with dry clay deposits along the bottom.
- Vertical or subvertical karst channels, circular or lenticular, are without any deposits or speleothems.

The objective of the speleological investigations at the Salman Farsi (Ghir) dam site was focused on morphological and local tectonically characteristics of the discovered caverns. An analysis of the speleogenesis was not foreseen in this stage of investigations. A comprehensive analysis of speleogenesis would need additional field investigations and laboratory tests.

The karst problem in Salman Farsi dam

The karst features in the dam site consist the cave and caverns and complicated fracture systems. Other karst features like Karrens and sinkholes and swallow holes are not distinguished in the area. There are two main karst spring at the two flank of the dam site. The one at the right is a cold water spring and at left there is a warm water hydrothermal karst spring which is assumed to be the reason of karst features of this side, however the karst features of the right side is said to be due to a fault zone on the right abutment of dam. As it is said before the main karst features are internal ones. The most karstified part is the right abutment with thousands of fractures and shafts and caverns and chimneys and caves. The most spectacular and troublemaking karst features in this side is the karstic Golshan cave with a volume of about ١٥٠٠٠٠m^{٣}. This space occupies a huge system of karst caves and shafts which is regarded as the most intensive karst problem in the dam site. (Figure ١).

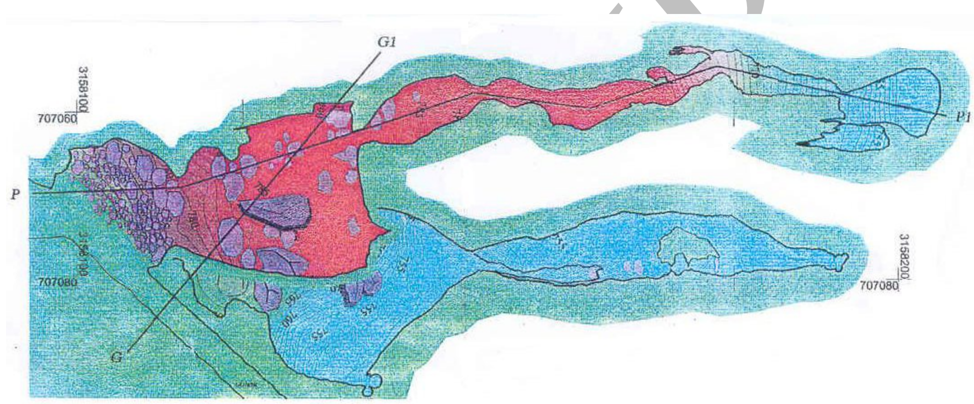


Figure (١): lateral cross-section of Golshen cave in Salman Farsi Dam

The extent of karst found calls for a systematic decision making process about its treatment. With the result of the speleological investigations available, such a process is now possible. It was therefore found meaningful to screen reasonable options for treating this area in a systematic manner, compares the different basic options selected from this screening. More than is ١٥ treatment options are suggested which among them five options present themselves in either sticking to the present alignment or bypassing the cave either upstream or downstream and one choice continuing the alignment through the ١٥th Lithological unit. The five selected options are as below:

١. Filling a part of the karsts and having a tall cut off wall while using the same grout curtain.
٢. Filling all the karsts and keeping the same grout curtain
٣. upstream by pass
٤. Down stream by pass
٥. Continuing the grout curtain to ١٥th lithological unit.

Option ١ is hardly feasible because of the following reasons: Passing the cave needs a concrete structure which has to resist the full hydrostatic pressure up to ١١٠ m water pressure. Given the caves maximum height of approximately ٨٠m, this would be an immense gravity wall within the cave.

The foundation of this wall is hidden by an unknown depth of blocky material. To excavate all this material is not realistic. However, a gravity wall of this size has to be founded on rock (and not on the blocky material).

Filling the cave by self compacting concrete (SCC) is no solution, given the unknown bottom of the cave below the blocky material. There is no control whatsoever in placing (SCC) over such a height. Sandy layers might be among the material under the blocks. This was typically found in other caves. Such layers would be critical leakage paths whiten the "treated" part of the cave open.

Since option ۱ is not conceivable, further investigations cover options ۳ and ۵ only. The technical and economical comparison has been done about them and is presented in table (۱).

Our very first and main objective in this research is to run the double porosity numerical model analyzing the water leakage which is always the worst problem in hydroproject to study its amount. Among the different options of this research and finding out the minimum leakage occurs in these five options. No need to say that the option of the minimum leakage would be the best choice of the model.

Table (۱): Table of Technical and Economical Comparison

NO.	**Alternatives**	**Karst Volume**	**Final Cost** (Billion Rls.)	**Technical Limitations**
۱	Filling all the karsts and having the same grout curtain	۱۵۰۰۰۰m^{۳}	۱۰۸	Cave's bed materials are not known and filling all the karst is so expensive
۲	Filling a part of karsts and having a tall out off wall while using the same grout curtain	۵۰۰۰۰ m^{۳}	۵۰	Risk of building a more than ۸۰ m wall on unknown bed material and the hydrostatic pressure on the wall
۳	Upstream bypass	۲۰۰۰۰ m^{۳}	۲۷	Grout curtain gets near to the lake
٤	Downstream bypass	۰	۲٦	The cave submerges and Hydrostatic pressure on the grout curtain while the nonactive karst systems will be activated
۵	Continuing the grout Curtain to lithological unit number ۱۵	۰	٦۰	The risk of encountering a new karst system

Salman Farsi dam modeling procedures:

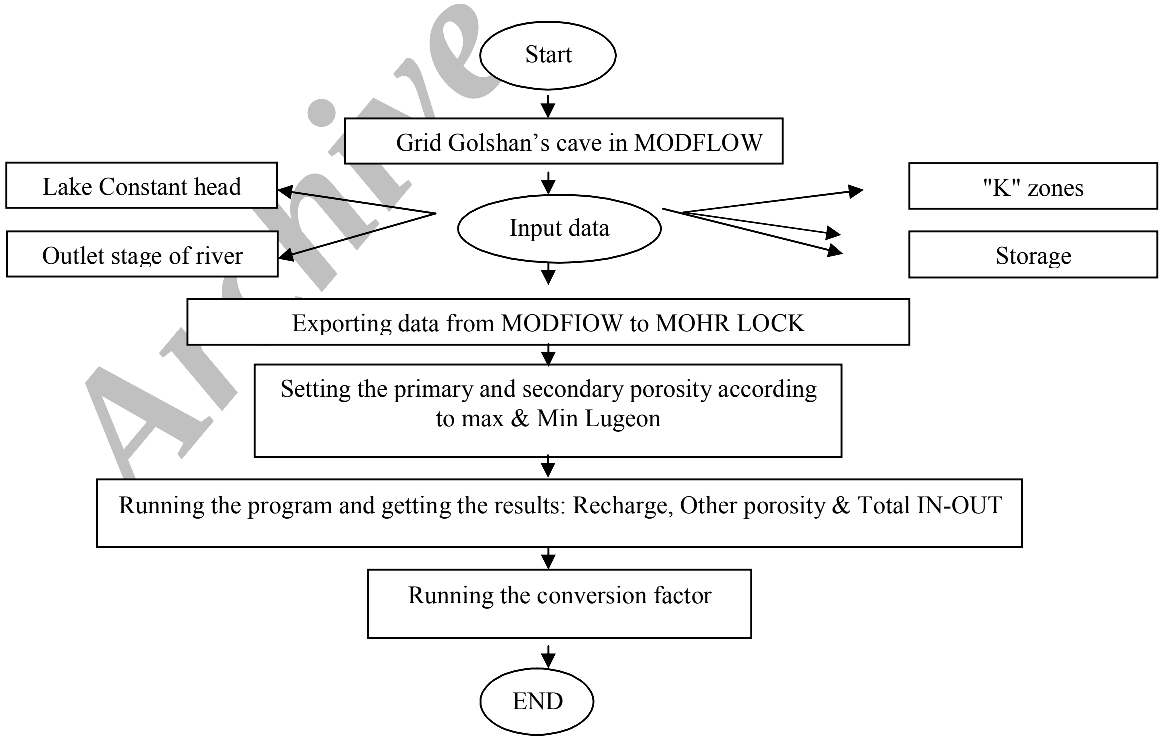
Among all the numerical models described for karst regions in this paper, double porosity continuum is identified as the best one to estimates the amount of leakage from a karstic bulk. To analyze the water leakage in this project and more specific in the right abutment and Golshans cave system, the model has been ran. Mentioned before, these are five remedial methods. The model has to compute the water leakage in each choice. The modeling procedures are presented here.

After preparing the geological maps, we should provide a mesh (nodding) of the area in visual MODFIOW program. The grid consists an area of ٥٠٠m×٢٠٠m which is meshed in ١٠m paces. Then the hydraulic specifications of the region such as hydraulic gradient and the rate of storage and the characteristics of the stone layers are introduced to the program. The very important factor that should be mentioned is the lugeon values of different sections of the right abutment. Then, all the input data in visual MODFLOW are exported to the double porosity model to be analyzed. MOHRLOCK program is the one that is used to work with in double continuum porosity space.

Double porosity has three kinds of outputs. One is the "coustant head OUT" and the other one "other porosity" and at last "Total IN-OUT". The base of decision and analysis is the value of "IN-OUT" which shows the difference between the water given from the lake to the abutment and the amount of water that has been kept in the area. The second amount of water is called "other porosity" that indicater the water which is conversed between the lake and the aboutment. But the leakage is assumed to be the water that has been added to the river discharge downstream.

Here a flowchart that shows the procedures of modeling and running the DCPE program is provided.

Figure (٢): Salman Farsi modeling procedures flowchart



Conclusion:

To Judge about the leakage amount of each alternative expressed before, considering two main element of "constant head" and "other porosity is necessary. Though the results of other porosity in all the choices are so close to each other, it is possible to put the value of "OUT constant head" as the base of Judgment.

According to the result in table (٢), it is simply obvious that in the first choice of filling the cave karst completely and continuing the same grout curtain, the minimum leakage would be reached. And at the same rate, the fifth choice also shows the same amount of leakage. The third choice also shows the same amount of leakage. The two other choices show higher rates of leakage. According to what expressed before and mentioned in economy and technical approach the first and the fifth choices aren't suitable remedies for the case. So as the leakage amount in third choice is as the same rate of the two others and besides, it′s a cheaper choice to run, the upstream grout curtain is regarded as the best chosen alternative for Golshan′s cave. The results are shown in table (٢).

Table (٢): The DCPE model results

No	Alternatives	In		Out		In-Out
		Constant head	Recharge	Constant head	Other porosity	
١	Filling all the karsts and having the same grout curtain	$٠.١٣٠١*١٠^{-١} m^{٣}/s$	$٠.٥٠٩٩*١٠^{-٢} m^{٣}/s$	$٠.٧٨٤٤*١٠^{-٢} m^{٣}/s$	٣٦٤٨ $m^{٣}$/day	$٠.٥٦١٥*١٠^{-١} m^{٣}/s$
٢	Filling a part of karsts and having a tall cut off wall while using the same grout curtain	$٠.١٣١٢*١٠^{-١} m^{٣}/s$	$٠.٥٣٠٦*١٠^{-٢} m^{٣}/s$	$٠.٨٦٩٢*١٠^{-٢} m^{٣}/s$	٣٦٤٠ $m^{٣}$/day	$٠.٥٧٤*١٠^{-١} m^{٣}/s$
٣	Upstream bypass	$٠.١٣١١*١٠^{-١} m^{٣}/s$	$٠.٥٠١*١٠^{-٢} m^{٣}/s$	$٠.٧٨٤٥*١٠^{-٢} m^{٣}/s$	٣٦٢٤ $m^{٣}$/day	$٠.٥٥٤*١٠^{-١} m^{٣}/s$
٤	Downstream bypass	$٠.١٣١٥*١٠^{-١} m^{٣}/s$	$٠.٥١٢٩*١٠^{-٢} m^{٣}/s$	$٠.٨٦٤*١٠^{-٢} m^{٣}/s$	٣٦٥٩ $m^{٣}$/day	$٠.٥٥٩*١٠^{-١} m^{٣}/s$
٥	Continuing the grout Curtain to lithological unit number ١٥	$٠.١٣٠١*١٠^{-١} m^{٣}/s$	$٠.٥٠١*١٠^{-٢} m^{٣}/s$	$٠.٧٨٩*١٠^{-٢} m^{٣}/s$	٣٦٢٤ $m^{٣}$/day	$٠.٥٥٤*١٠^{-١} m^{٣}/s$

Suggestions:

١. Assuming lag time as in nature in the software. The model is designed to transfer water through the Matrix cell into the conduit. Although the same thing happens in nature, but it takes time not simultaneously. However the coefficient which is designed to work out the same sake is not successful.

٢. The sorting of matrix and conduit cells in this program is also one of the troublesome making ones. Because in nature, the real system works differently and it causes two troubles.
One: As we said the most part of flow in a karst area is transmitted through a small percentage of it around ١٠%, but the program default doesn't provide it.
Two: The matrix and conduit cells are defined next to each other. But in a real karst system just the boundary cells of them are neighbors and the other matrix cells are bulk and conduit cells form a conduit.

٣. Maybe the assumption of a middle cell (not matrix/not Conduit) somewhat a metaphase cell (not ١/not ٠) solves the problem.

٤. Using other models to analyze the karst water flow and comparing the results. For example the CAVE hydrogeological model or the Discrete fractures Model.
٥. Double porosity model is just used for regional works, developing the model to be qualified for even global works is also a good suggestion for researchers.
٦. Karst modeling is a new and a never ending branch of groundwater study and it needs to be considered more.

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