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Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 05

October 2016, P.P.2145-2150

Research on Red Rock Permeability Properties and Its Control to Water Project

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Abstract: Certain permeability capacity exists in red beds rock due to the structural plane, weathering fracture and other fractures exist in red beds rock, which causes permeability happen to dam foundation rock and then led to problems of reservoir water loss and decrease of stability of rock and benefits etc. Permeability of dam foundation rock is one of the common engineering geological problems in red beds water conservancy and hydropower engineering. Main geological controlling factors have been confirmed through the analysis of forming process mechanism of permeability problems of red beds dam foundation etc., permeability features of rock, permeability features and laws of different lithological combinations and corresponding geological basis and analysis methods have been provided for the design of anti- permeability for hydraulic dam.

Keywords: *water project, red rock permeability, permeability and control feature, lithological combinations*

1. Introduction

Red beds distribute all over the world and in China, it mainly distributes in northwest, southwest and south China; however, Sichuan Basin is with the most red beds distribution, which is the most continuous and classic. Sichuan Basin is with dense population, industry, agriculture and other basic industries are well developed. However, red beds area of Sichuan Basin lacks water resources, runoff duration distribute unevenly, draughts and floods happen frequently, which has restricted the agricultural and industrial development seriously; therefore, most of water conservancy irrigation projects in Sichuan province locate at red beds area; for hydropower resources, they locate at plateau area of western Sichuan, but the development conditions are good as they are near to power load center and transportation is convenient. However based on the literature, most of existing literatures make random analysis and discussion for some problems with combination of specific engineering cases and there is almost no systematic research on geological problems in water conservancy and hydropower engineering at red beds area of Sichuan Basin. There is only one research monograph named “Red Beds and Dam” written by Ruichun Xu at present, which has studied the geological problems in water conservancy and hydropower engineering at red beds area by discussing the related geological problem of Gezhouba project[1]; “Geological Research and Application of Red Beds Soft Rock Engineering of Dam Foundation” written by Zongli Wan and Dexin Nie mainly discussed the geological problem of dam foundation engineering of hydropower station located at the third lay of red beds at upper reaches of northwest Yellow River; there are no other similar works[2].

For this, the author has made systematic research on geological problem of main water conservancy and hydropower engineering in red beds rock of Sichuan Basin based on practice of over one hundred big and medium sized water conservancy and hydropower engineering at red beds area of Sichuan Basin in recent twenty years; its purpose is to implement water resources development strategy for “building another Dujiangyan Dam” at red beds of Sichuan Basin, develop and protect water conservancy and hydropower resources reasonably and effectively and provide certain theoretical support and method basis for geological prospecting work of water conservancy and hydropower engineering at red beds area[3].

2. Permeability features of different categories of red beds rock

In water conservancy and hydropower engineering, the permeability feature of rock is generally expressed by the results of water pressure test-rock permeability rate (q) and its unit is Lu. 1Lu means that under the pressure of 1MPa, the pressed flow of water of 1m rock is 1.0L/s. The permeability feature of rock is based on 2×4×3=24 categories. Based on the results of water pressure test data of 3899 sets of red beds rock of 22 water conservancy and hydropower engineering in Sichuan Basin, attain the permeability results of different categories of rock through statistics, as shown in table 1 and table 2.

Table 1: *Group of red beds rock mass containing soluble salt water rate and the lithology and the relationship between the states of weathering*

The lithology combination	The state of rock mass weathering permeable rate and statistics group

Name	Number	Strong weathering	Statistical group number	Weak weathering	Statistical group number	fresh	Statistical group number
Sandstone class	1	62.3	6	45	13	21.6	46
Sand and mudstone interbedding class	2	35.2	12	29.6	25	25	41
Argillaceous rocks and sand	3	36	23	68	6	9.6	23
Argillaceous rocks	4	51.2	14	39	236	5.8	253

Table 2: *Ordinary red layer permeable rate and lithology and the relationship between the state of weathering*

The lithology combination		The state of rock mass weathering permeable rate and statistics group					
Name	**Number**	**Strong weathering**	**Statistical group number**	**Weak weathering**	**Statistical group number**	**fresh**	**Statistical group number**
Sandstone class	1	34.2	36	23.6	75	6.32	223
Sand and mudstone interbedding class	2	33.6	54	19.5	78	6.36	423
Argillaceous rocks and sand	3	26	26	26.5	6	3.54	25
Argillaceous rocks	4	29.3	52	59	254	5.21	123

Statistical results of table 1 and table 2 indicate that:

(1) Permeability rate of same kind of rock of red beds rock including soluble component is bigger than the common red beds without soluble component, which is the result of karst function of red beds layer.

(2) For category 1 to 4 of different lithological combinations of red beds rock, permeability rate decreases with the increase of argillaceous rock.

(3) Weathering state red beds rock has bigger influence on the permeability rate of rock. The overall decrease trend of permeability rate of strongly weathered rock, weakly weathered rock and fresh rock; for fresh red beds rock, except for the permeability rate of sandstone and mudstone layer is bigger than 10Lu, all the rest permeability rates are smaller than 10Lu, which belong to week permeable rock; while no matter strongly weathered rock or weakly weathered rock is a category rock or b category rock, its permeability rate is between 10-100Lu, which belong to medium permeable rock[4].

It can be learnt that the overall weathered red beds rock near surface belongs to medium permeable rock and the overall fresh rock is weak permeable rock. The permeability of red beds rock changes from weathered rock within weathering shell near surface to the underlying fresh rock, its permeability is with “shell-core binary” structure. Weathered rock is permeable “rock” and fresh rock is relatively impermeable “core”, this structure is determined by the geological process formed by permeable zone of rock at diluvium layer[5-7]. In the survey and design of red beds rock leakage and leakage control, corresponding analysis calculation and leakage control design can be made as long as attain the permeable features of permeable “shell” as well as the upper bound of relatively impermeable “core”.

3. Leakage and anti-leakage design

3.1 Project summary

Leakage and anti-leakage design at dam area is one of the important problems in dam engineering of hydraulic structures, which affects the benefits and safe operation of engineering. The leakage of reservoir meeting the standards needs to meet following two conditions:

1. Leakage amount:

Qs: quantity of reservoir seepage, Q_{allow}: allowable seepage amount of reservoir;

$$Q_s < Q_{allow} \quad (1)$$

2. Seepage deformation:

$$J_{\max} < J_{allow} \quad (2)$$

J_{max}: max hydraulic gradient in rock, J_{allow}: allowable hydraulic gradient of rock.

3.2 Confirmation of allowable seepage amount of reservoir (Q_{allow})

At red beds area, because the implementation of anti-leakage is relatively easy and engineering quantity also takes up small proportion. Followed allowable seepage index of red beds area has been proposed; anti-leakage requirements are considered based on the principle of “weak leakage or basically not leakage”; allowable seepage amount Qalow can be determined based on table 3.

There are Qingyijiang River, Tuojiang River, Fujiang River and Jialing River running across Sichuan Basin[8-10]. Based on the average flow statistics of hydrologic stations set at the upper, middle and lower reaches of four rivers, the average flow over years of four rivers is Qb=475m3/s. This is a basic magnitude concept about the above rivers in Sichuan Basin, which has been taken as one of basic parameters in this paper to confirm the allowable seepage amount of red beds rock permeability model.

If no regulating reservoir:

$$\begin{aligned} Q_s < Q_{allow} &= 0.005 - 0.01 Q_b \\ &= (0.005 - 0.01) \times 475 = 2.375 - 4.75 m^3/d \\ &= (2.052 - 4.104) \times 10^5 m^3/d \end{aligned} \quad (3)$$

If have regulating reservoir:

$$\begin{aligned} Q_s < Q_{allow} &= 0.01 - 0.03 Q_b \\ &= (0.01 - 0.03) \times 475 = 4.75 - 14.75 m^3/d \\ &= 4.104 \times 10^5 m^3/d \end{aligned} \quad (4)$$

3.3 Confirmation of allowable hydraulic gradient (J_{allow}) of reservoir

It needs to consider about two situations for the selection of allowable hydraulic gradient (Jallow), when there is fractured zone formed by weak interlayer in the rock, it is controlled by fracture zone of weak interlayer[11]; If there is no fractured zone formed by weak interlayer, it is controlled by permeability of rock. The critical hydraulic gradient (Jcr) of weak interlayer in the paper takes its average value as the critical hydraulic gradient value of each kind of interlayer based on field test result statistics of related engineering weak interlayer, as shown in table 3.

Table 3.*Part of the project critical hydraulic gradient of different categories of weak interlayer fracture zone and allow the hydraulic grade*

Project		**A rock type**	**B rocks and mud**	**C clip mud rock type**	**D mud**
The critical slope	Statistical group number	8	8	3	6
	The average	3.62	6.23	13.26	3.25
	The maximum value	7.15	12.36	17.54	7.15
	The minimum value	1.25	2.54	10.23	5.12
J_{allow}		1.77	3.65	3.36	3.24
note		$J_{allow}=J_{cr}/2$			

Allowable hydraulic gradient is attained by considering certain security coefficient based on critical hydraulic gradient. According to the regulations of “Geological Prospecting Specifications for Water Conservancy and Hydropower Engineering” GB50487－2008, critical hydraulic gradient is generally 1.5-5 times of allowable hydraulic gradient and it can select 2.5 times for particularly big projects[12-14]. The level of water conservancy and hydropower engineering at red beds area is generally not high and usually there is no particularly big and high level projects, therefore, the paper selects situations with higher safety coefficient generally and select upper limit value at two times.

4. Numerical simulation analysis of seepage of dam foundation

This section adopts 3D-Modflow software to simulate the changing rules of each model at leakage quantity (Q) and max hydraulic gradient (Jmax) of rock with the changes of heights of dam (H) and length of impervious curtain (Lc) under different lithological combinations and topographic features and analyzes the main influencing factors of seepage of dam foundation and impact assessment for engineering.

4.1 Seepage model

According to the statistics, the thickness of strongly weathered zone at red beds area is generally 2-6m and thickness of weakly weathered zone is 3-9m. During simulation calculation, select their average values 4m and 6m respectively, and then consider about if there is permeable zone formed by weak fracture zone in fresh rock of dam foundation (consider about the height at 1m, its permeable coefficient is considered based on the permeable coefficient of strongly weathered rock) and divide dam foundation seepage rock into two categories[15-16]. Define the dam foundation categories as following: A type of dam foundation is the dam foundation without permeable zone formed by weak fracture zone in fresh rock; B type of dam foundation is the dam foundation with permeable zone formed by weak fracture zone in fresh rock.

4.2 Calculation content and results analysis

Under given water head H of 10m, 30m, 50m and 70m, calculate A and B foundation dams of sandstone type (1) and mud rock (2), seepage quantity (Q) and max hydraulic gradient in rock (Jmax) under different lengths of curtain (Lc) (depth crossing weathered zone) are as shown in Figure 1 and Figure 6.

Following conclusions have been drawn based on analysis of calculation results:

1) Under the situation that the other conditions are the same, the seepage quantities of dam foundations of sandstone with dissoluble rock, mudstone with dissoluble rock, sandstone without dissoluble rock and mudstone without dissoluble rock are different and seepage amount presents a decreasing trend, which presents the differences in two kinds of rock with dissoluble components and seepage performance of common red beds. The seepage amount of dam foundation of sandstone with dissoluble rock is the biggest, which is about four times of that with the smallest seepage amount.

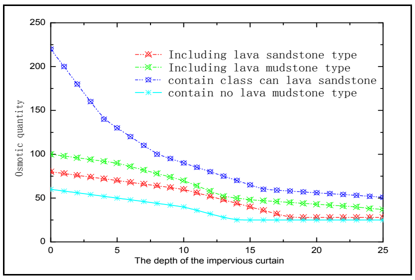

Figure 1 *Class A dam foundation under the condition of 10 m head dam osmotic quantity relation with anti-seepage curtain depth calculation results*

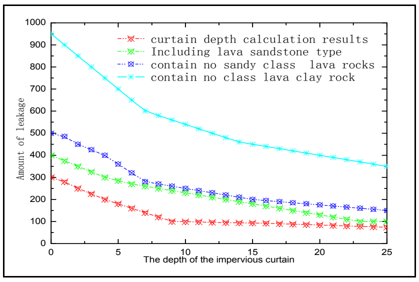

Figure 2 *Class A dam foundation under the condition of 30 m head dam osmotic quantity relation with anti-seepage curtain depth calculation results*

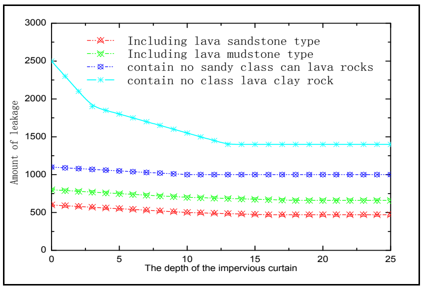

Figure 3 *A class under the condition of the dam foundation in the 50 m head dam osmotic quantity and anti-seepage curtain depth calculation results*

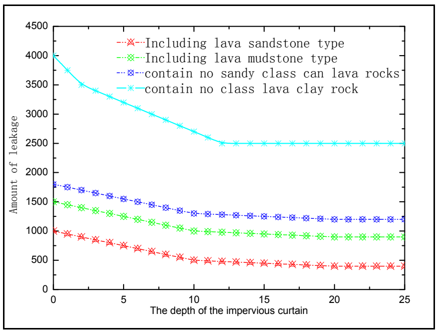

Figure 4 *A class under the condition of the dam foundation in the 70 m head dam osmotic quantity and anti-seepage curtain depth calculation results*

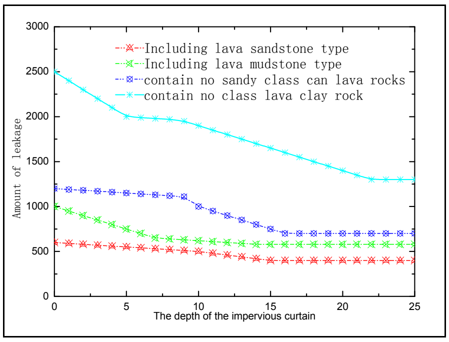

Figure 5 *B class under the condition of the dam foundation in the 50 m head dam osmotic quantity and anti-seepage curtain depth calculation results*

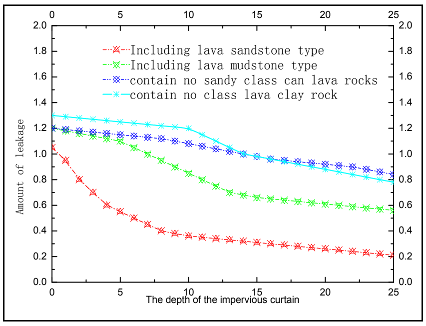

Figure 6 *B class under the condition of the dam foundation in the 70 m head dam osmotic quantity and anti-seepage curtain depth calculation results*

2) Under the situation of the same water head conditions, with the increase of depth of impervious curtain, the seepage quantity of various lithological dam foundation decreases. When impervious curtain is at weathered rock permeability zone (take the thickness of strongly weathered zone at 4m and thickness of weakly weathered zone at 6m in the model, that is when the length of curtain Lc＜10m, it indicates that curtain is within the weathered rock permeability zone), the magnitude of seepage decrease is bigger; When it exceeds 10m, impervious curtain is in fresh rock, at this moment, the quantity of seepage decreases relatively slowly with small magnitude. It is indicated that the depth of weathered rock permeability zone is the turning point for the change of seepage quantity; when the depth of

impervious curtain is bigger than permeability zone, the effectiveness of increase of curtain for the decrease of seepage quantity is not obvious as that in permeability zone, as shown in Figure 1-Figure 6.

3) Under the condition that the depths of impervious curtain are the same, for the same kind of lithological dam foundation, the bigger water head, the bigger seepage quantity. Especially at the high water head, small change at water head will cause great difference in seepage quantity change.

4.3 Numerical simulation analysis of seepage around the dam

Based on the topographic features of river (ditch) slope at red beds area, simulation of seepage around dam can be divided into straight slope (a) and ridge slope (b) which is commonly seen in hilly region. Simulation Figure for straight slope (a) is as shown in Figure 7 and simulation Figure for ridge slope (b) is as shown in Figure 8.

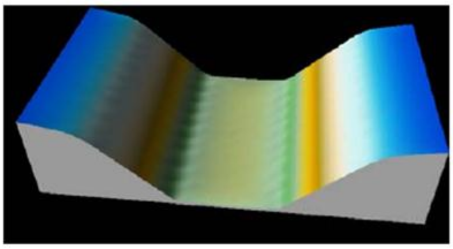

Figure 7 *straight slope (a) model*

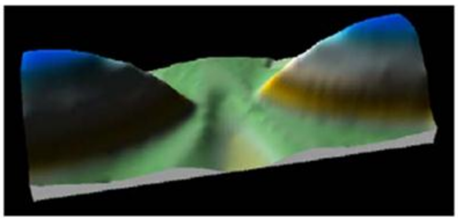

Figure 8 *ridge slope (b) model*

Following conclusions can be drawn based on analysis results:

(1) Under the situation that all other conditions are the same, seepage quantity around the dam will decrease with the increase of the length of impervious curtain (Lc).

(2) Analyze from the lithological perspective: the seepage quantities around the dam of four different lithologies of sandstone with dissoluble rock, mudstone with dissoluble rock, sandstone without dissoluble rock and mudstone without dissoluble rock present a decreasing trend. However, the seepage quantity around the dam of sandstone with dissoluble rock is the biggest, which is 5-8 times bigger than the smallest and the difference is big.

5. Conclusions

(1) In general, the hydraulic gradient of red beds rock is easy to be satisfied, seepage deformation and damage will not happen to red beds rock or weak interlayer, which may possibly relate to the high mud content of red beds rock as well as big allowable hydraulic gradient in rock and weak interlayer.

(2) Seepage quantity can meet the requirements under most situations. For storage reservoir in irrigation project, because the allowable seepage amount is small, the project seepage under some situations may not meet the requirements.

(3) It needs to specially point out that the above calculation results represent the calculation results under seepage model conditions (geographic and geomorphic conditions and overall hydrogeological parameter of red beds rock (rock seepage rate and allowable hydraulic gradient is the total quantity value of seepage rate at red beds rock attained from statistics)) as well as the analysis judgment based on its results; it only represents the overall changing trend of seepage under different situations as well as basic steps and principle of seepage evaluation and can't replace the seepage analysis and judgment of specific projects. It needs to make specific analysis and judgments for specific projects; in particular, the parameters of specific project can't be replaced by hydrogeological parameters of various rocks listed in this paper.

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