

## Formation of Groundwater with Strong Alkalinity under Dam Foundation and its Significance

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**Abstract.** During operation, the interaction between liquid and solid phases within the seepage domain around a dam-site tended to be intensified due to engineering activity, and as a result some special water chemical types formed behind the curtain. By using in-situ investigation, sampling and data analyzing, they were dealt with, taken 5 hydropower stations located in the southern CHINA as cases. It was shown from the data that the groundwater locally was alkalized, i.e.  $\text{pH} > 10.0$ . It is believed that this kind of groundwater was produced from interactions among water, rock and curtain. As to its significance, following aspects can be identified: (1) the state between water solution and carbonate mineral  $\text{CaCO}_3$  being near- even over-saturated; (2) the distribution being in consistent with that of white precipitates from some drainage holes behind the curtain. Finally, it is pointed out that the geochemistry leading to the groundwater with strong alkalization would have a negative effect on the mechanical behavior of rock masses concerned.

**Keywords:** Strong Alkaline Groundwater, Water-Rock-Curtain Interaction, Dam Foundation

### 1. Introduction

It is well-known that groundwater in the real world is a kind of good solvent, and as a result there are lots of reactants in the solution. Although the formation and evolution of its quality is complicated, some patterns might be still identified. The study showed that the groundwater in the shallow crust is usually in the range of  $\text{pH} = 3 \sim 10$ , and in most cases,  $\text{pH}$  value is just between 6 and 8, i.e. with weak acidity, neutrality and weak alkalinity, respectively[1]. This is greatly due to wide existence of carbonic acid in nature and its buffering to the variation of  $\text{pH}$ [2].

However, it has been found that the basic characteristics of groundwater quality around several dam-sites located in the southern CHINA were quite different from that under pure natural conditions, in which as to the former,  $\text{pH} > 10$ , meaning the groundwater in position being strongly alkalized. As a result, some special water chemical types were produced. The attention should be paid to that how this kind of groundwater quality was formed, and how its potential effects on project's operation would be.

In this paper, the formation of strong alkalinity of groundwater around dam-sites and its significance are studied, which are all located in the southern CHINA. The objectives of this study are firstly to deepen the knowledge about the influence of engineering, such as a dam and curtain, on water chemistry within the domain, and secondly to get some information about engineering's safety operation.

### 2. Main Chemical Characters of Groundwater with Strong Alkalinity

5 hydro-power plants listed in Table 1 are situated in the southern CHINA, in where it is within the tropical and sub-tropical region with annual precipitation of over 1200mm, and the vegetation was quite developed within the drainage basin. The major hydro-structure of all projects mentioned was composed of a concrete dam and others. The surface water in a reservoir is soft water, i.e. less than  $150\text{mg}\cdot\text{L}^{-1}$  (expressed by

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CaCO<sub>3</sub>) and usually of dissoluble aggression on solid phases contacted. During the period of project's operation, it becomes one of main recharge sources to the groundwater around a dam-site. As a result, the seepage and water chemical field were developed within the domain, in which the coupled action from multi-fields and –phases were produced.

Some water chemical indexes listed in Table 1 are synthetic. From Table 1, following aspects could be identified. (1) The percentage varies from project to project, i.e. from 4.35% to 44.44%, meaning that the groundwater with strong alkalinity occurred only locally behind the curtain. (2) The main difference in quality at the same time between the surface water and the groundwater with strong alkalinity lies in that the former had less TH(hardness, expressed by CaCO<sub>3</sub>), i.e. TH=6.50~45.00mg·L<sup>-1</sup>, while the latter had larger one, i.e. TH=13.70~160.35 mg·L<sup>-1</sup>. Additionally, TDS (total dissolved solids) value of the groundwater was larger than that of the surface water, up to even over 2 times. (3) Due to difference in quality between discharge and its recharge source within the system, different water chemical types were produced. Furthermore, some special water chemical types were developed in the process of strong alkalization, which are unlikely to occur under the pure natural condition. It indicates that within the system, the complicated physico-chemical interaction took place not only between water and rock, but also between water and the curtain.

Table 1 Statistics of main chemical indexes of groundwater under dam foundations

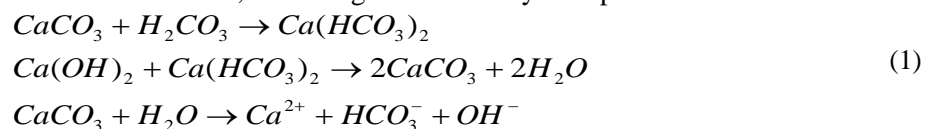
Project	Lithology	Water body	Water chemical index			Type	Time for sampling	
			pH	TH/mg.L <sup>-1</sup>	TDS/g.L <sup>-1</sup>			
Jin Shui-tan (21)	granite	A	7.23	6.50	0.028	HCO <sub>3</sub> ·SO <sub>4</sub> -Ca·Na	1995~2002	
		B	10-1	10.04	33.50	0.082	CO <sub>3</sub> OH-Ca	20.00%
			10-5	10.13	35.00	0.085	CO <sub>3</sub> OH-Ca	
Si Tang (21)	tuff	A	7.16	7.00	0.027	HCO <sub>3</sub> ·Cl·SO <sub>4</sub> -Na·Ca	1995~2002	
		B	3-7	10.68	35.50	0.115	OH·CO <sub>3</sub> -Ca·Na	44.44%
			4-4	10.58	41.00	0.103	OH·CO <sub>3</sub> -Ca·Na	
			5-5	10.79	61.00	0.119	OH-Ca·Na	
			7-1	10.46	37.00	0.104	OH·CO <sub>3</sub> -Ca·Na	
Shui Kou (19)	granite	A	7.17	19.50	0.030	HCO <sub>3</sub> -Ca·Na	1998~2003	
		B	9-4	10.31	13.70	0.151	CO <sub>3</sub> -Na	28.57%
			38-16	10.93	81.45	0.129	CO <sub>3</sub> -Ca	
			10-5	11.55	160.35	0.228	OH-Ca·Na	
Chen Cun(4)	sandstone	A	7.40	45.00	0.061	HCO <sub>3</sub> -Ca·Mg	1991~1992	
		B	12-5	10.20	67.45	0.147	CO <sub>3</sub> -Ca	9.09%
Xin A'jiang(32)	sandstone	A	7.89	18.50	0.050	HCO <sub>3</sub> -Ca	1992~1999	
		B	24-1	11.55	38.90	0.297	OH-Ca·Na	4.35%

Note: The number in bracket in the first column denotes times for measuring; A, B in the third one are surface water and groundwater, respectively, while x-x denotes dam-section x and drainage bole x. Percentage in the last one is the ratio of number of samples listed to the total number for sampling at that time.

### 3. Formation of Groundwater with Strong Alkalinity

#### 3.1. Interaction among water, rock and curtain

It is known from Table 1 that TH value of the groundwater behind the curtain was much larger than that of the surface water as its recharge source. According to the original water chemical data, this chemical index was mainly composed of ion of Ca<sup>2+</sup>. It is believed that there are two sources relative to the increase of this cation in concentration. One is from dissolution of carbonates occurred in discontinuities of rock masses and another from cement (or grout) materials contained in the curtain. As to formation, there are two mechanisms which could be identified. One may be described as that the surface water with soft and some dissolved aggressive CO<sub>2</sub> moves towards the dam foundation, following reactions may take place:

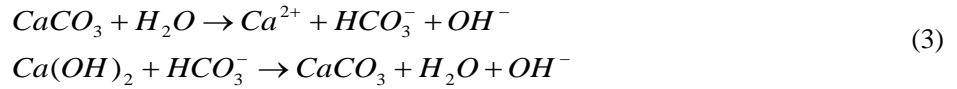


If pH>8.3, some of HCO<sub>3</sub><sup>-</sup> would be transferred to CO<sub>3</sub><sup>2-</sup>, i.e.



From the above reactions, it is known that in the process of seepage transit within the domain, the carbonate in discontinuities of rock masses were dissolved firstly, and as a result, dissoluble  $Ca(HCO_3)_2$  formed. If contacted with cement materials in the curtain, the film of calcite around the cement would be produced firstly, and then be into water solution through hydrolysis.

Another mechanism is that when the surface water still with soft dissoluble aggression but no aggressive  $CO_2$  moves towards the dam foundation, the reaction with the above solid phases may be described as:



Besides, the incongruent dissolution from minerals like silicates has the contribution to the variation of the groundwater quality concerned.

Obviously, the results from the above reactions would lead to the increase of ions of  $Ca^{2+}$  and  $OH^-$  in concentration, and consequently, the groundwater with alkalization even local strong alkalization might appear behind the curtain.

### 3.2. Relative to engineering activities

As known, during the construction for the projects listed in Table 1, rock masses with some permeability under the dam foundation were grouted with normal cement to form the curtain for anti-seepage. This kind of foundation engineering has an influence on water quality usually from two aspects. One is direct, described as (3). Another is indirect, i.e. by which the seepage behavior was altered within the domain. Generally, the anti-seepage effect of the curtain can be realized from (1) lengthening of seepage path per unit time, and (2) the relative impermeability itself. Due to these two functions, the seepage behavior behind the curtain tends to be inactive, and so it is suitable for richness of such ion as  $OH^-$ , which is mostly from the hydrolysis of carbonates in this case. As a result, the groundwater behind the curtain was alkalized, even locally strong alkalized, and some special chemical types were formed, shown in Table 1.

## 4. Significance of Strong Alkaline Groundwater

### 4.1. Reflection of degree up to saturation

There are some physico-chemical factors affecting on groundwater quality, but dissolution- precipitation happened between liquid and solid phases are most common. As discussed in section 3.1, the alkalization of groundwater behind the curtain is relative not only to the hydrolysis of carbonates, but to the dissolution of cement contained in the curtain as well. The study shows that on the basis of chemico-thermodynamics, SI (saturation index) model can be used to reflect the state between water solution and some mineral, such as  $CaCO_3$ , meaning that if (1)  $SI < 1.0$ , the state was under-saturated; (2)  $SI = 1.0$ , the critical state between dissolution and precipitation; and (3)  $SI > 1.0$ , the state up to over-saturated[3, 4]. It is interesting to note that the relation between the above state and pH value under the certain condition will be.

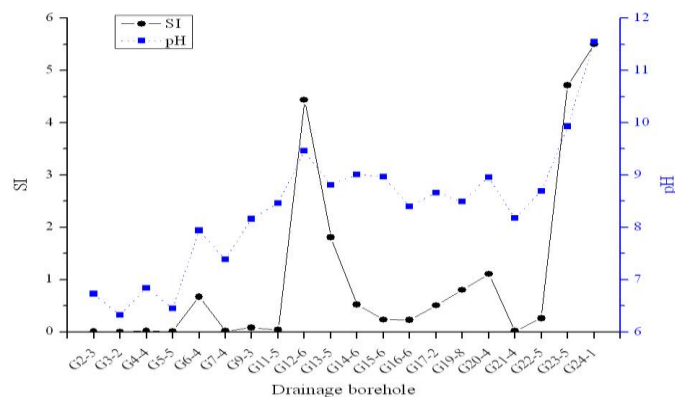


Fig.1: Profile of pH and SI of groundwater along Xin'anjiang dam-axis

Fig. 1 is a profile along a dam-axis to show the distribution of pH and SI of the groundwater behind the

curtain in Xin An'jiang project, in which SI was with respect to CaCO<sub>3</sub>. In the figure, G2-3 and G24-1 were located in the right and left abutment of the dam, respectively, while others were between these two. It indicates that the variation of its pH and SI had almost the same tendency, i.e. increasing from the right to left dam abutment. Of 20 sampling points, there were 5 points with SI>1.0, all located in the bed and left dam abutment, and at these points, pH was relatively bigger and vice versa. Therefore, it may be drawn that the positive correlation existed between pH and SI in this case.

#### 4.2. Reflection of calcareous precipitate in extent

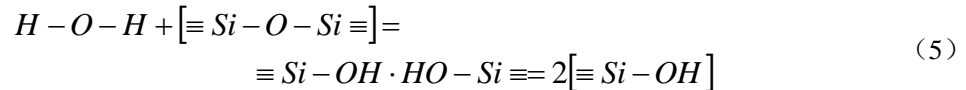
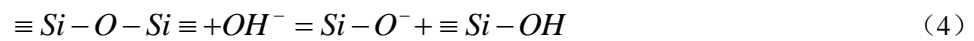
On in-situ investigation, it was found that various precipitates with different colors occurred around dam-sites listed in Table 1, of which white precipitate was more common in distribution. After sampling and measuring, it appears that this kind of precipitate was mainly composed of CaO and LOI (loss on ignition), which in sum was up to even over 80%. After crystallized, CaO would be transferred into CaCO<sub>3</sub>. Compared with pH data, we found that some correlation existed between precipitates and pH value of the groundwater in position. Taking Xin'anjiang project as an example. It was shown from in-situ investigation that white precipitate occurred from the bed to left dam abutment, i.e. from dam sections 7 to 24, while the precipitate with other colors was distributed mainly within the right dam abutment, i.e. from dam sections 2 to 6[5]. From Fig. 1, it is known that the groundwater in dam sections with white precipitate was obviously alkalized even locally strong alkalized, and was up to saturation even locally over-saturation, whereas the groundwater in dam sections with other precipitates was of pH=6.0~8.0, and was under-saturated.

Compared with SI result in calculation, we also found that the number of drainage boreholes with white precipitate was much than that of the groundwater with SI>1.0, meaning that at some boreholes, although the groundwater was under-saturated, white precipitate might still occur. This is because on the one hand, the solubility of like CaCO<sub>3</sub> in the process of alkalization tends to be down. And on the other hand, the dissolution of calc-silicates within the water-rock system, such as anorthose, would have a contribution to breaking up of the system, i.e. CaCO<sub>3</sub>+H<sub>2</sub>O, with chemical equilibrium.

#### 4.3. Reflection of potential chemical damage

From Table 2, we know that soluble SiO<sub>2</sub> of the alkaline groundwater in projects listed in Table 1 is in the range of 13.46 to 55.39 mg·L<sup>-1</sup>, all higher than that of its recharge source (i.e. surface water). So it is believed that the phenomenon, i.e. soluble SiO<sub>2</sub> richening in alkaline groundwater, is quite common. This is because the solubility of SiO<sub>2</sub> will increase with pH increasing, particularly if pH>9.0.

The formation of the alkaline groundwater behind the curtain is suitable not only for dissolution of SiO<sub>2</sub> but also for possible inducing of chemical damage. The study showed that the geochemistry leading to the increase of OH<sup>-</sup> in concentration has a negative effect to the mechanical behavior of rock masses concerned[6, 7]. Under the certain environment, the reaction between the mineral (i.e. SiO<sub>2</sub>) and water, which will result in the chemical damage, may be described as:



Consequently, the micro-fissure will be further developing, in which WRI (water-rock interaction) will be chemical mainly, and at some stage of this process, the macro-mechanical behavior of the rock masses concerned may be affected on. Under the certain condition, it may lead to the occurrence of seepage instability within the domain, which will have an effect on project's operation.

Table 2 Statistics of soluble SiO<sub>2</sub> of alkaline groundwater in dam-sites

Project	Water body	Soluble SiO <sub>2</sub> /mg·L <sup>-1</sup>	Project	Water body	Soluble SiO <sub>2</sub> /mg·L <sup>-1</sup>
Jin Shui-tan (21)	A	10.72~11.28 (11.00)	Shui Kou (19)	A	9.56~10.78 (10.17)
	B	16.39~19.98 (17.78)		B	20.78~27.24 (23.36)
Shi Tang (21)	A	10.79~11.56 (11.18)	Xin'Anjiang (32)	A	4.07~5.62 (4.85)
	B	17.80~26.93 (22.99)		B	9.56~15.93 (13.46)

Note: Number in bracket in the third and sixth column denotes the averaged one; others are the same as mentioned in Table 1.

## 5. Summary and Conclusion

During the period of project's operation, the formation of alkaline even local strong alkaline groundwater (pH>10.0) behind the curtain was caused by both water-rock chemical interaction and man-made engineering. It indicates that in position, the state between water and carbonate mineral (such as  $\text{CaCO}_3$ ) was up to near-even over-saturation, and its extent in distribution was in coincidence with that of white precipitate within the domain. The hydro-dynamic condition to form strong alkaline groundwater was inactive, meaning that the thicker boundary layer between liquid and solid phases exists, and as a result, the dissolved aggression on the latter tends to be weak. In this case, it seems not suitable to only use bicarbonate alkalinity for appreciation of groundwater with dissolved aggression. Therefore, it is recommended that the general alkalinity, which is composed of  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$ , be used as an index for appreciation, instead of bicarbonate alkalinity. Finally, it is pointed out that under the certain condition, the geochemistry resultant in alkalization of groundwater would have a negative effect to mechanical behavior of rock masses concerned, to which attention should be paid.

## 6. Acknowledgments

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## 7. Reference

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