Solubility of limestone and seepage problems in the left abutment of the Marun dam, southwest of Iran

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Abstract

In this study, seepage phenomena through the left abutment of Marun dam are investigated. The Marun dam is a 170 m high rock fill dam, which regulates the waters of the Marun River, serves power generation, and flood control and provides irrigation needs. The dam site lies in the Zagros Mountains of southwest Iran. This region presents continuous series of mainly karstic limestone, marl, shale and gypsum ranging in age from Cretaceous to Pliocene. The region has subsequently been folded and faulted. All underground excavations are sited in the left abutment. The spacing of the diversion tunnels and pressure tunnel is considered to be acceptable, meaning relatively short, thus requiring 2 row grouting curtain into both embankments. Prior the reservoir impoundment, the concrete plug was constructed into the middle section of second diversion tunnel. Upstream section of tunnel was not concreted. During the first reservoir impounding, the

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old karst channels along 'Vuggy Zone' cut by the second diversion tunnel were reactivated and leakage occurred. The total amount of water leakage through the left bank of Marun dam was about. The unlined second diversion tunnel had a key role in connecting reservoir with karst conduit system. On the basis of detailed engineering geological analysis, the concept of remedial works was carried out. The main points of this concept are one of row grout curtain extension up to the section with shaly interbeds declared as watertight Asmari sequence (close to the watertight Pabdeh formation) and plugging of accessible section of main karst channel by concrete. In order to determine the seepage direction and karstification pattern, solubility studies were done. Also pinhole, XRD and XRF tests were carried out. The major joint system and interbedding cracks have predominant role in karst evolution process. Hydrogeological role of joints, perpendicular to geological structure, is not negligible. As a result of these studies, seepage paths have been identified in the karstic limestone in the left abutment of the dam.

Keywords: Solubility; Karst; seepage; Asmari limestone; Joint; Aperture; Diversion tunnel; Dispersive materials

1. Introduction

The Marun dam site is located on the Marun River, in Khuzestan province of southwest Iran, approximately 19 kilometers north of Behbahan city (Fig.1).

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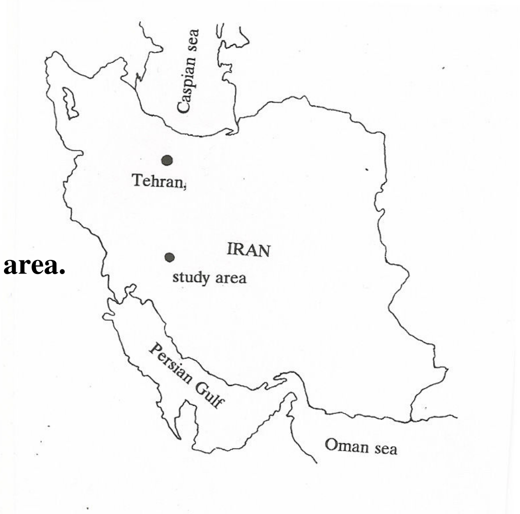

Fig.1. Location of the study area.

The 170m high rock fill dam regulates the waters of the Marun River. Also, it serves power generation, flood control and irrigation needs (Fig.2).

Fig.2. A photo of Marum dam (downstream).

During the first reservoir impounding, the old karst channels along "Vuggy Zone" cut by the second diversion tunnel were reactivated and leakage occurred. Discharge started in gallery LA-3 about 40 l/min (Fig.3 and 4).

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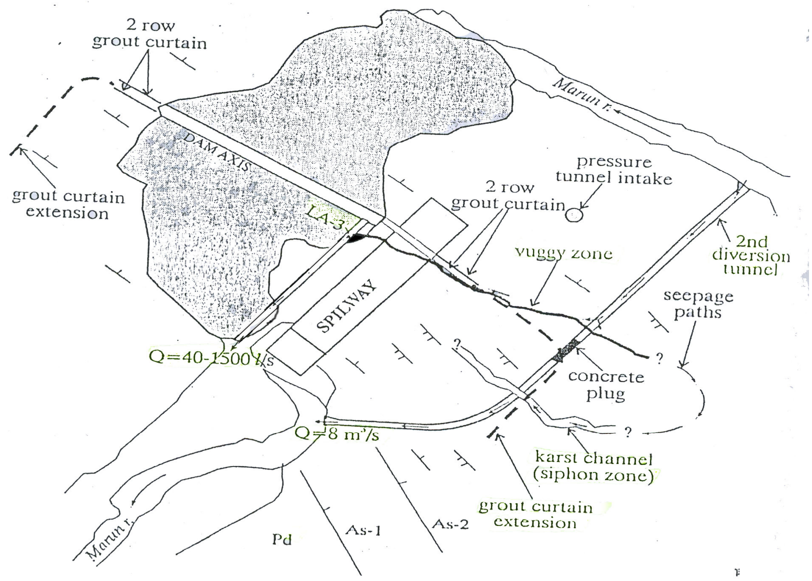

Fig.3 Simplified sketch of Marun dam site.

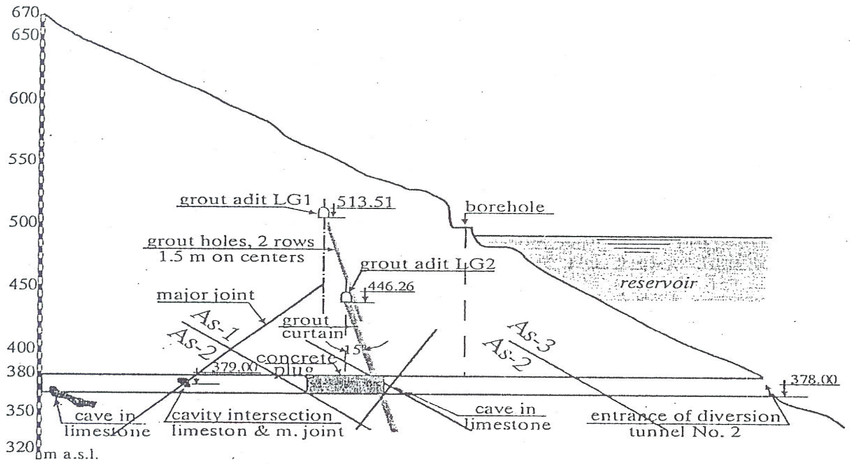

Fig. 4. A profile of the second diversion tunnel in the left abutment.

The reservoir level was 40m only. As a consequence of washing process discharge from LA-3 in few days increased to $1.5m^3/s$. Simultaneously, much larger leakage appeared at several places in the second diversion tunnel, and at a few more points in galleries and tunnels in the left abutment. The largest discharge occurred in the second diversion tunnel (Fig. 5).

Fig.5. A photo of the second diversion tunnel in the left abutment.

The total amount of water leakage through the left bank of Marun dam was about $10m^3/s$. All appeared from tunnels and galleries only. No spring was observed along the left bank of the river in the downstream of the dam site.

Many hydraulic structures founded upon carbonate rocks are safe against solution attack because the groundwater is already saturated with calcium carbonate before it reaches the structure. However, there are other cases, where this is not so and water seeping through foundations, drain and filter, may be unsaturated and therefore capable of dissolving the carbonate rock minerals. According to data published by Snow (1969); James and Lupton (1978); James and Kirpatrick (1980); James and partners (1981); James and Lupton (1985); Milanovic (2000); Turkmen (2001, 2003); Laksiri and partners (2005);

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Mohammadi and Raesi (2005), and Ghobadi (1986, 1997, 2005), if foundations of a dam contain soluble mineral, then water seeping through them will create gaps. So any rock, which contains soluble minerals and is part of a hydraulic structure such as a dam, reservoir, or tunnel, should be suspect. Therefore, for design purpose, it is required to know the solution characteristics of rocks, i.e., solubility and solution rate constant and the composition and temperature of groundwater. They may combine with anticipated seepage flow velocities through the relevant component of the structure and foundations to provide an estimate of the rates of solution and how they effect it service life.

2. Geological setting

The dam site is situated in the Zagros Mountain in southwest Iran. This region presents continuous series of sedimentary ranging in age from Cretaceous to Pliocene. This sequence mainly consists of limestone, marl, shale and gypsum (Fig.6). The oldest units at the site are Eocene limestone, marl and shale, which are exposed upstream of the dam site. Overlying these rocks is the Asmari formation, a series of limestone unit's with marl, dolomite and shale. The Asmari formation is major ridge-forming rock in the site area and forms the entire foundation of the dam. The dam is situated on the north flank of anticline on the low karstified middle Asmari limestone (As-2). The lower Asmari limestone (As-1) consists of a relatively permeable

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"Principal Vuggy Zone" (PVZ), which is overlain by impervious shale. The upper Asmari limestone (As-3), just downstream of the dam is very kastified. It consists of well developed voids which locally occur with traces of dissolution phenomenon continuity. These dissolutions are more evident along fissuring or stratification planes in cores or outcropping surfaces. The Asmari limestone is covered by the much karstified overlying Gachsaran Formation, with a number of sinkholes, caves and fissures (Fig.7).

A few minor faults traverse the dam site. These faults are the result of shearing stresses developed in the bedding. Most of these faults are roughly parallel to the strike of major joint sets and they dip steeply. Vertical displacements along the faults are small, ranging from a few centimeters to about 2 m. Fault surfaces, explored by adits, were found to be slightly open at the surface but closed in many cases at depth. Several joint sets cut the Asmari limestone at the site. The rock mass is cut by two major sets of joints. One major joint set strikes 030 degree and dips 80 degree NW and the other major joints set strike 300 degree and dips 70 degree NE (Fig.8). Most of the joints exhibit some calcite filling, clay staining and weathering. Joint spacing ranges from 10 to 80 cm. Bedding planes, in conjunction with these joints, control the solubility in the Asmari limestone. Shearing along bedding planes was evident from place to place in adits by clay gouge between separated bedding surfaces. Fissures and cavities are often filled with erodible materials such as fine-grained silt or clayey silt.

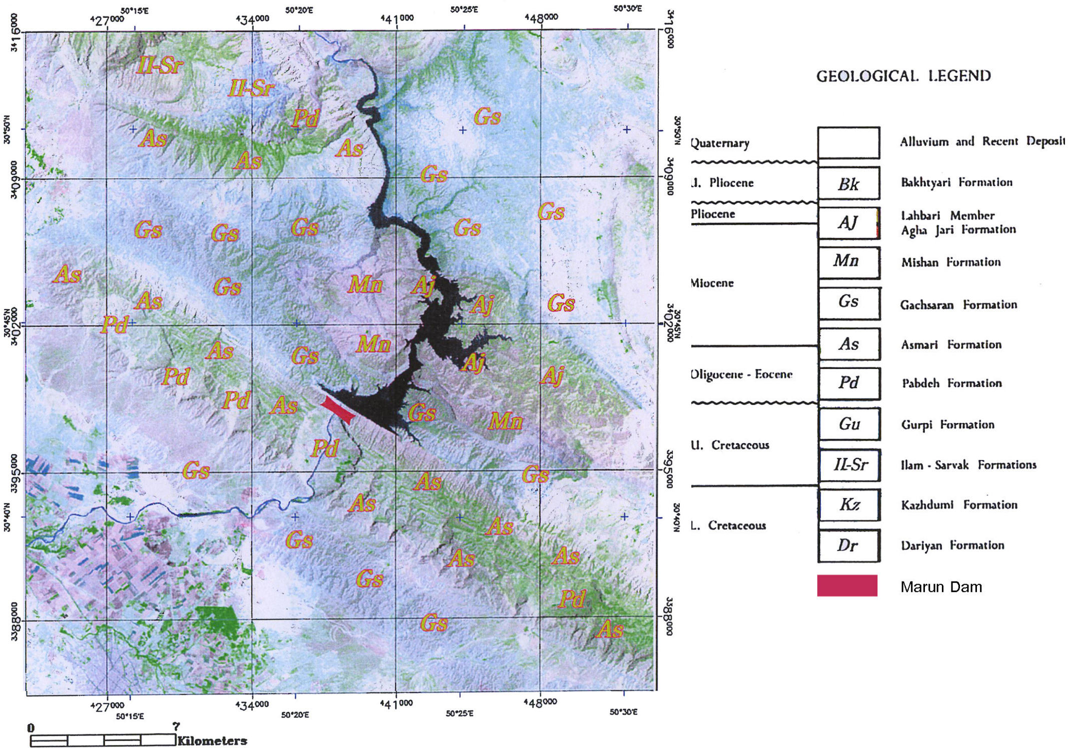
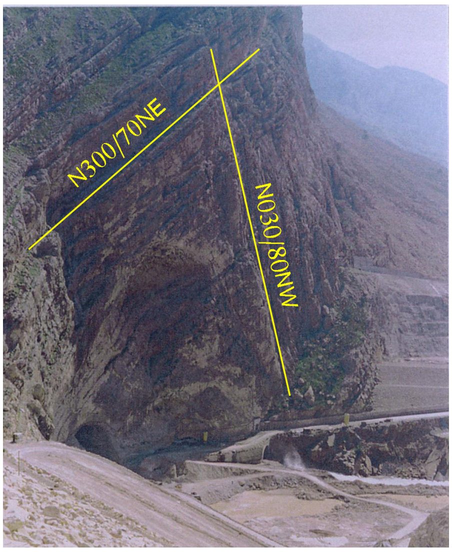


Fig.6. Geological map of the investigation area.

Fig. 7. The dam reservoir is covered by the very karstified Gachsaran Formation, with a number of sinkholes, caves and fissures.

Fig.8. Several joint sets cut the Asmari limestone at the site. The rock mass is cut by two major sets of joints. One major joint set strikes 030 and dips 80 degree NW. The other major joints set strike 300 degree and dips 70 degree NE.



3. Laboratory works.

3.1. Solubility test

In order to assess the solubility of Asmari limestone, it is necessary to know not only the geological characteristics of the rock masses, but also the physical properties. to this end, the fieldwork was aimed at gathering of the geological and geotechnical data and collection of representative core samples for laboratory studies. Core samples were collected from the boreholes. The specimens were prepared by cutting the core into required size using disc saws. Table 1 shows specificat-ions of core samples.

In this research, in order to consider the effect of aperture of joints on the solubility of Asmari limestone, artificial joints of 0.5, 1.5, 2and

3 mm aperture were made from core samples of 100 to 152 mm length.

Water circulated through the artificial joints in a closed cycle. Testing the rock samples with different sizes in aperture was carried for 52 days. Every 9 days, the amount of discharge from each specimen was measured. Test conditions were fixed throughout the test period. The water pressure was maintained 5 psi, temperature was maintained between 0-5 degree centigrade and the acidity (pH) was between 5.5-6.0.

Table 1. Specification of core samples used in this research

Sample No.	Water content (%)	Specific gravity	Porosity (%)	Dry density (g/cm^3)
Mr1	0.75	2.45	1.81	2.4
Mr2	7.07	2.45	14.78	2.08
Mr3	7.35	2.45	15.27	2.07
Mr4	9.16	2.45	19.06	1.98
Mr5	6.28	2.45	13.34	2.12
Mr6	1.98	2.45	4.64	2.33
Mr7	1.13	2.45	1.31	2.38
Mr8	9.74	2.45	19.28	1.97

Analysis of data showed that the increase of aperture of joints would cause an increase in the diffusion phenomenon. This process will cause more sedimentation at the smaller aperture 0.5 mm. Artificial joint of 0.4 mm aperture closed after 20 days and the amount of discharge in artificial joint of 0.5 aperture reduced %42 during 72 days (Ghobadi 1997,2005). In this research the reduction of water discharge through aperture of 0.5 mm and the increase of water discharge through aperture 1, 1.5,2 and 3 mm during 52 days (Fig.9).

A known volume of water was circulated through the drilled rock sample cylinders at a predetermined flow rate using the apparatus. The calcium ion concentration in circulating solution was taken as a measurement of the dissolved calcium carbonate in water. Also, the calcium ion concentration had been determined by atomic absorption spectroscopy (A.A.S.).

The rate of solution of samples was measured using solution of carbon dioxide of different concentration in the phases. Typical plots are given in Figure10. From these plots the computer program was able to extract a value of K_c. Average of solubility rate constant (K_c) in cm/s was determined by the following equation:

$$\frac{V}{A}\times\frac{d_c}{d_t}=K_c(C_s-C)^n$$ (White, 1977)

Where V is volume of water, A is the area of rock surface exposed to aqueous solution at any time t, d_c and d_t are change in concentration and time respectively, C_s is saturated concentration, C is concentration and $n=2$. The average of solution of limestone samples were $K_c=3.15\times10^{-7}\,cm/s$ for 8 samples (Table 1). It can be concluded that the solubility of Asmari limestone is low (Ghobadi 2004, 2005b).

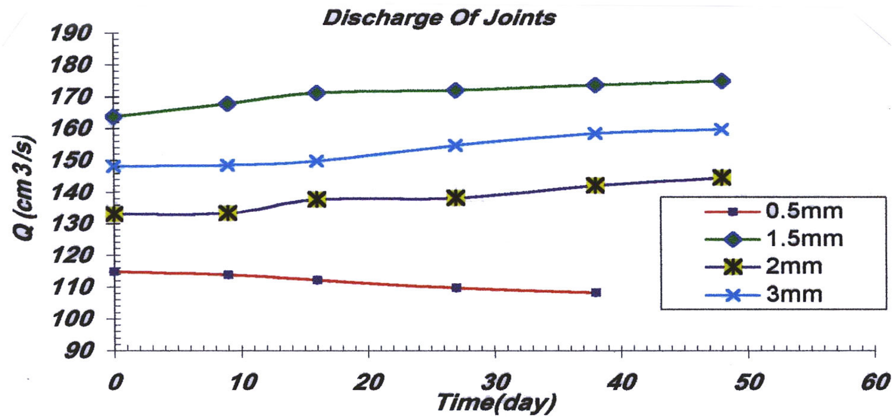


Fig.9. The reduction of water discharge through aperture of 0.5 mm and the increase of water discharge through aperture 1.5, 2 and 3 mm during the testing period.

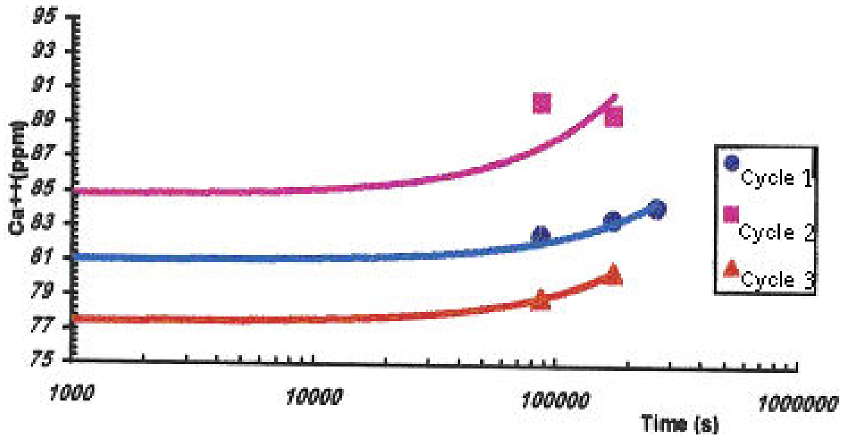


Fig.10. Dissolution of calcium carbonate versus log of time for three phases in carbon dioxide of different concentration. Phase 2 selected for determined of K_c.

3.2. X-ray fluorescence (XRF)

X-ray fluorescence is a valuable tool in determining the chemical composition of rock. The aim of this test was to identify CaO and

MgO in the composition of a rock. Four core samples collected from boreholes in the left abutment were studied using XRF to determine the variability of SiO_2, Al_2O_3, CaO and MgO in the rock composition (Table 2). According to the result of this test it was found that CaO in all samples is less than 50% and MgO in four samples is between 2.17 and 20.81. This means that solution phenomenon in Asmari limestone is low (Ghobadi, 2004, 2005a).

Table 2. The result of X-ray fluorescence (XRF)

Samples no.	Mr1	Mr4	Mr5	Mr6
SiO_2%	2.79	1.83	3.07	1.47
Al_2O_3%	0.92	0.67	1.45	0.76
CaO%	28.43	41.13	49.88	48.19
MgO%	20.81	10.03	2.17	4.73

3.3. X-ray diffraction (XRD)

In order to assess the mineralogy of karstic filling materials, samples were collected from galleries in the left abutment. Results of X-ray diffraction analyses indicate that filling materials typically contains quartz, iron oxides, kaolinite, illite, smectite(montmorillonite) and expandable lattice mixed-layer clay minerals. The most abundant clay mineral is kaolinite, and the main expandable lattice clay minerals are smectite (Table 3).

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Table 3. The results of X-ray diffraction (XRD)

Sample no.	Mineralogy
MrLd1	quartz, iron oxides, kaolinite, illite, smectite,
MrRAB2	Quartz, kaolinite, illite, smectite
MrRA2B1	Quartz, kaolinite, illite
MrRD1	Quartz, feldspar, kaolinite, iron oxides, , smectite
MrLD2	Quartz, kaolinite, illite, smectite
MrR2E	Quartz, kaolinite, iron oxides, smectite

3.4. Pinhole test

The pinhole test provides one method of identifying the dispersive characteristics of clay and silty soils. In order to assess the dispersive characteristics of karstic filling materials, samples were collected from galleries in the left abutment (Table 4). The results of pinhole tests showed that most of the samples are dispersive. This means the karstic fissures and cavities are mainly filled with erodible materials such as fine-grained silty sand or clayey silt. If the filling of cavities or the old karst channels connecting the reservoir with one of the watercourses was completely eroded, it would cause enormous water losses, which would be very difficult to stop by constructional measures. Rising and dropping groundwater tables, as well as increasing and decreasing quantities of seepage and drainage water occurring continuously or temporarily, indicate erosion or self-sealing processes which often follow each other, hereby indicating the transport of erodible materials.

Table 4. The result of pinhole tests

Sample No.	Filling materials	Classification
MrLd1	Clay	Dispersive
MrRAB2	Clay	-
MrRA2B1	Silt	Dispersive
MrRD1	Silt	Dispersive
MrLD2	Silt	Dispersive
MrRAE2	Silt	Dispersive

4. Conclusions

In this research attempts wrer made to examine the effect of aperture of joints on solubility of carbonate rocks of Asmari formation in Marun dam site in Iran. According to the results of this experimental work, it was found that solution phenomenon for Asmari limestone is low. But the aperture of joints controls the amount of discharge of joints, which is an important geotechnical factor on the dam construction. Detailed geological and geotechnical investigations are therefore necessary to evaluate engineering behavior of jointed rock mass undergoing karstification process.The analysis of laboratory works indicated that the increase of aperture of joint will cause an increase in the solution phenomenon and consequently the amount of discharge in joints will be increased with time. Also, this study showed that apertures smaller than about 0.5 mm are unlikely to be

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dangerous in most foundation in carbonate rocks. An appropriate grouting program can be designed for rocks containing lager apertures.

Fissure and cavities are often filled with erodible materials such as fine grained silty and clayey silts. These fine grained materials are dispersive. The infillings are likely to be transported into these watercourses provided the hydraulic gradient would become high enough. If such fissures were emptied by erosion they could transport large amounts of water.

The left abutment of Marun dam contains a net of water conducting channels, cavities and even underground water-courses that together feed the second diversion tunnel. This network had been formed during the geological past; its components have a preferred orientation into the left abutment especially towards the second diversion tunnel. The second diversion tunnel has a key role in connecting reservoir with karst conduit system.

In order to determine the karstification pattern, detailes hydrogeological studies, additional investigation boreholes to monitor fluctuations in groundwater level are recommended.

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