Influence of Joint in the Phenomena of Solubility of Limestone

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Abstract

Current research, that involves laboratory investigations into the phenomena of solubility, uses circulation equipment that has been developed to study the enlargement of joint aperture. This paper describes the preliminary results of laboratory experiments on ten different length and width of samples, which show that the flow rate through the fissures increases with time as the fissures enlarge. However, when longer samples were used, the flow rate velocity decreased as fissure enlargement decreased. The results from the analysis of the 50 tests performed indicated that the length of sample decreases as the flow rate increases, e.g. the flow rate in sample to length of 100 mm after the period of three months increases from 116.7 to 130.3 ml/s. The flow rate in sample to length of 300 mm increases from 106.1 to 111 ml/s. It was then possible to predict the relationship between enlargement of joint aperture and time, and also Furthermore, to predict the smallest joint aperture which will cause dangerous progressive solution in limestone over 90 day period. The

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paper shows fissures smaller than about 0.5 mm in aperture are unlikely to be dangerous in most foundation in carbonate rocks.

Introduction

According to James & Lupton (1978), the principles governing the dissolution of minerals describe laboratory tests which confirm the validity of the predictions. Water flow through both jointed rock and porous granular material is considered. it shows that the rate at which the surface of a mineral or rock retreats depends primarily upon two properties of the mineral, namely:

(i) The solubility(c) of the mineral, which is the amount which can be dissolved in a given quantity of solvent, at equilibrium, and

(ii) The rate of solution of the mineral, which is the speed at which it reaches the equilibrium concentration. The solution rate constant (k_c) is further dependent on the flow velocity and temperature of the solvent and concentrations of other dissolved salts in it.

James (1981) concluded that assessment of the potential for progressive solution of a dam foundation required determination of the following:

(i) The chemical composition of the in flowing seepage water;

(ii) The sizes and distribution of open joints.

He concluded also that joints with apertures less than about 0.4 mm were unlikely to be dangerous in most foundations in carbonate rocks, thus confirming one of the main conclusions of James & Kirkpatrick (1980) and Ghobadi(1977, 2001).

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Shapes of enlarged fissures depend on rock solubility, dissolution rate constant, and flow velocity. High velocities cause gradual tapers, and flows tend to increase rapidly as rock dissolves. Flow rates through the fissure represented by the ratio of flow rate to initial flow rate (Q/Q_0) increase slowly and steadily, Q_0 is the initial flow rate through the fissure; and Q is the flow rate after a given period of time. Therefore, Q/Q_0 represents the proportional increase in flow rate.

Critical sizes of fissures, those which are large enough to lead to rapid enlargements and flows, within the service life of a structure, can be calculated and site investigation procedures designed to find them (Sadeghi & Pasaris 1996, Sadeghi & Khosravi 2001, Sadeghi & Khosravi 2002).

According to James (1992) it is important to evaluate the rates and consequences of dissolution. Chemical grouts should only be used to seal narrow joints and fractures in rock, which are inaccessible to cement grouts, typically less than 0.5 mm wide. If dissolution poses a threat, design will seek measures to remove it, perhaps by moving the project to another site or specifying different construction materials. If a radical solution is not feasible a means to ameliorate the problem will be sought, for example by grouting a foundation.

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Apparatus

Circulation equipment has been developed to study the parameters controlling solubility (Fig. 1).

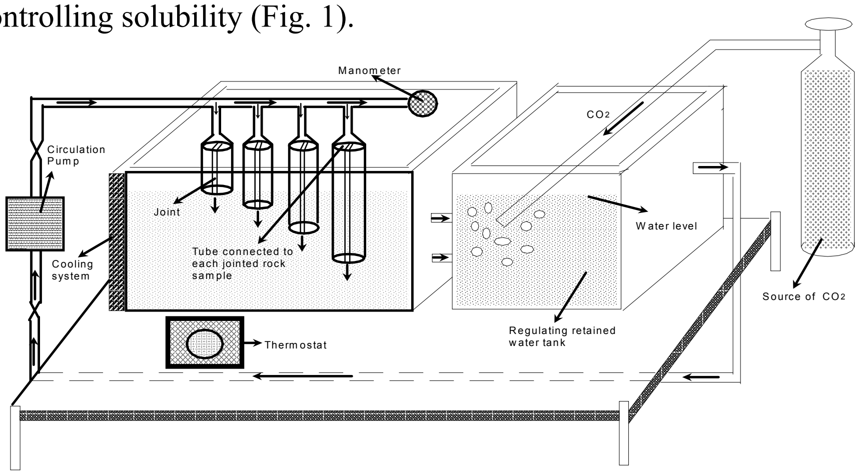

Fig.1. Apparatus for measuring solubility and circulation of water through calcium carbonate rocks (modified after Ghobadi 1997).

The apparatus consists of a speed-frame base that was constructed to raise the equipment 300 mm from the floor. This was done to allow insulation and pipework to be fitted underneath the apparatus. Two insulated double-layer tanks with removable lids were then fitted to the base. A water circulation system was then installed using 28 mm copper and PVC piping.

The water circulation was achieved using an electric pump and a pressure-meter was incorporated to monitor the water pressure through the pipeline.

The five branches were fitted 100 mm apart and the water flow was reduced by a 4 mm bore nozzle at the end of each branch. Two refrigeration units (cooling system) were installed to reduce the water

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temperature to the required level and two electric fans were used to cool the refrigeration unit motor. A thermostat was fitted to monitor to control the water temperature throughout the system.

Rock sample Preparation

The core specimens used for the assessment of the influence on length and width of joint in the solubility test were taken from the site. The limestone specimens were obtained by drilling cores with at least 50 mm diameter and using different lengths. The samples which were cut longitudinally to study the influence on length and width of joint in solubility were prepared as follows:

(i) The test samples used for the assessment of the influence on length of joint in solubility were cored with at least 50 mm diameter employing a 100, 150, 200, 250 and 300 mm length using a small diamond blade saw.

Two 6 mm holes were then drilled 20 mm from the ends of each core for clamping purposes. The cores were then cut longitudinally again using the diamond blade saw. The clamping bolts were then fitted with the appropriate sized spacing washers between the two halves. The spacer washer thicknesses were 1 mm for all samples. The completed core sample was then wrapped using cellux parcel tape. The core was then coupled to the rubber membrane and secured with a jubilee clip ready for connection to the apparatus.

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(ii) The test samples used for the assessment of the influence on width of joint in solubility were cored with at least 50 mm diameter employing a 150 mm length using a small diamond blade saw.

The specimen preparation procedure adopted for these tests were identical to those employed for the tests used for the influence of the joint length. The space washer thicknesses were 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm and 2.5 mm .

Experimental Method

In order to determine the flow rate and enlargement of sample joint the following procedures were implemented:

1. The samples were oven dried at 105°C for 12 hours (before every test).
2. The samples were cooled in the desiccator, and were weighed with an accuracy of 0.01g .
3. The pH was controlled by a pH meter every hour (before every test the pH meter was calibrated with Buffer solution). The pressure of water was kept at 68 kPa.
4. Every 3 days the water used in the test was changed, due to the concentration of calcium ion saturation.
5. The flow rate through the fissure was measured for each sample every 10 days in order to determine the variation of flow rate (measurement was taken three times for 15 seconds and then average was calculated for each second).

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Temperature of the water was kept between 0-5°C. Carbon dioxide at a pressure of 68 kPa was injected into the water, by a 30 kg capsule and a polythene pipe, with a diameter of 6 mm.

Test Results and Discussion

The flow rate through the fissure increases with time as the fissure enlarges. The relationship between variations of flow rate versus time for different length joint over the period of three months is shown in (Fig.2).

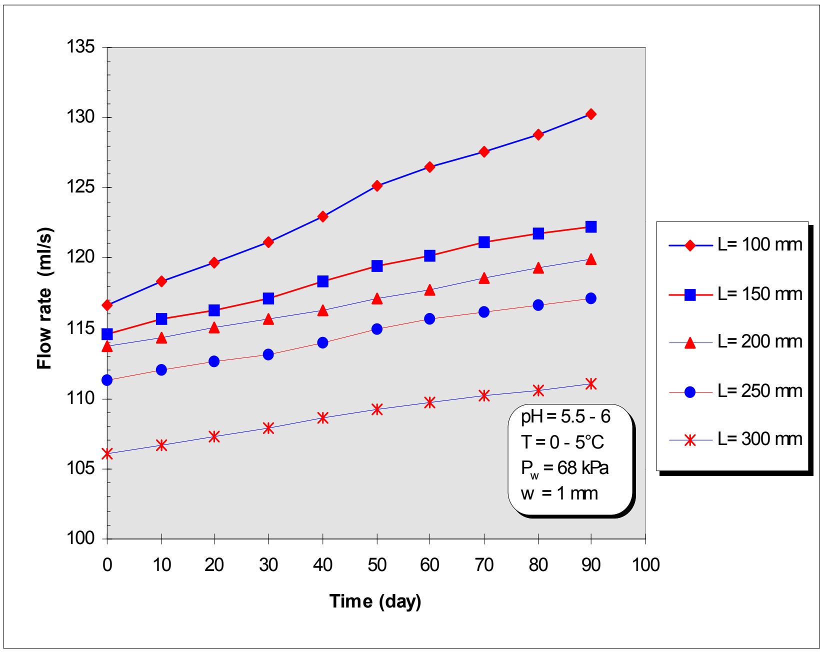

Fig. 2. Relationship between variations of flow rate versus time over a 90 day period.

As this figure shows, from the analysis of the 50 tests performed, as the length of sample decreases, the flow rate increases. e.g. The

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flow rate in a 100 mm length sample after the period of three months increases from 116.7 to 130.3 ml/s.

The flow rate in sample to length of 300 mm increases from 106.1 to 111 ml/s. Summary of variation of flow rate and enlargement of fissure over a period of three months is shown in Table 1.

Table 1. Summary of variation of flow rate and enlargement of fissures over a 90 day period (different length joint).

Sample No.	1	2	3	4	5
L = mm	100	150	200	250	300
D = mm	50	50	50	50	50
w = mm	1	1	1	1	1
Date	Q_{ave} ml/s	Q_{ave} ml/s	Q_{ave} ml/s	Q_{ave} ml/s	Q_{ave} ml/s
2.06.2002	116.7	114.6	113.7	111.3	106.1
12. 06.2002	118.3	115.7	114.3	112	106.7
22. 06.2002	119.7	116.3	115.1	112.6	107.3
1. 07.2002	121.1	117.1	115.7	113.1	107.9
10. 07.2002	123	118.3	116.3	114	108.6
20. 07.2002	125.1	119.4	117.1	114.9	109.2
30. 07.2002	126.5	120.2	117.8	115.7	109.7
10.08.2002	127.6	121.1	118.6	116.2	110.2
20. 08.2002	128.8	121.7	119.3	116.7	110.6
30. 08.2002	130.3	122.3	119.9	117.1	111
% $\Delta Q/Q_0$	11.6	6.7	5.4	5.2	4.6
% $\Delta w/w_0$	3.9	2.2	1.8	1.7	1.5
Enlargement of fissure (mm)	0.039	0.022	0.018	0.017	0.015

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As this table shows, from the analysis of the 50 tests which were performed, sample No. 1 (w =1 mm, L=100 mm) indicates a 11.6% increase in flow rate, sample No. 2 (w =1 mm, L=150 mm) indicates a 6.7% increase in flow rate, sample No. 3 (w =1 mm, L=200 mm) indicates a 5.4% increase in flow rate, sample No. 4(w=1 mm, L=250 mm) indicates a 5.2% increased in flow rate and sample No. 5 (w=1mm, L = 300 mm) indicates a 4.6% increased in flow rate. It seems that with increasing fissure length , flow rate decreases.

The relationship between length of sample and weight reduction is shown in (Fig.3).

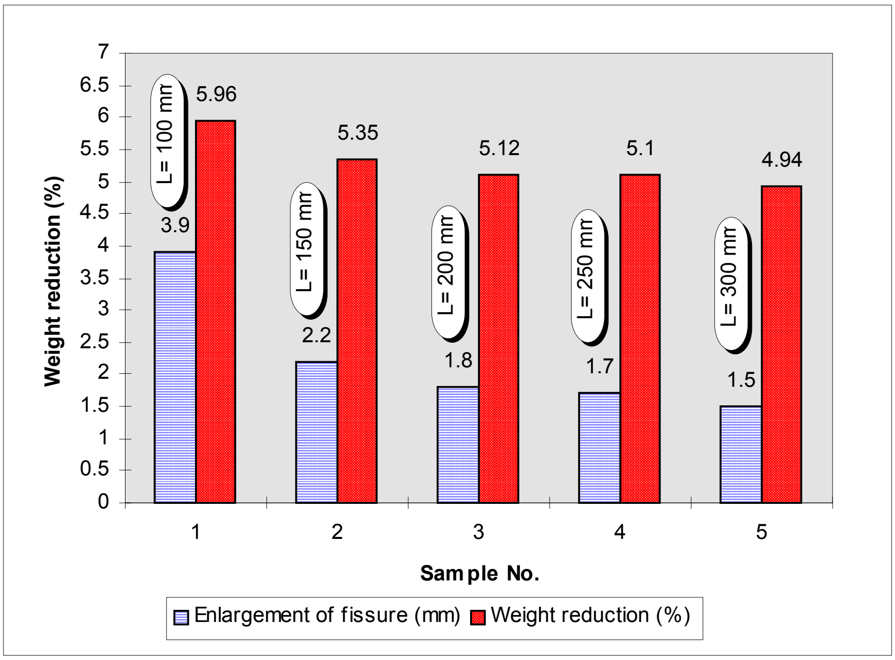

Fig. 3. Relationship between length of sample, weight reduction and enlargement of fissure aperture.

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It can also be seen from this figure and Table1 that after the three months period, the result of fissures enlargement at different lengths is as follows:

Sample No. 1 to fissure aperture of 1 mm increases to 1.039 mm, sample No. 2 to fissure aperture of 1 mm increases to 1.022 mm, sample No. 3 to fissure aperture of 1 mm increases to 1.018 mm, sample No. 4 to fissure aperture 1 mm increases to 1.017 mm and sample 5 to fissure aperture 1 mm increases to 1.015 mm. It seems with increased the fissure length, fissure enlargement decreases.

A summary of weight reduction of sample tested over a period of three months is shown in Table 2.

Table 2. Summary of variation of weight of rock samples at the period of three months (different length joint).

Sample No.	1	2	3	4	5
L = mm	100	150	200	250	300
D = mm	50	50	50	50	50
w = mm	1	1	1	1	1
Samples weight (g) Before test	527	779	1026.6	1247.4	1512.7
After 30 days (g)	518.1	767.4	1012.3	1228.6	1491.8
After 45 days (g)	510.7	757.8	999.7	1212.7	1473.8
After 60 days (g)	504.4	748.9	988.6	1199.6	1457.8
After 75 days (g)	499.4	742.2	980.5	1189.7	1446.1
After 90 days (g)	495.6	737.3	974.0	1183.7	1438.0
% Weight reduction	5.96	5.35	5.12	5.10	4.94

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It can be seen from the (Fig.3) and Table 2 that with increased weight reduction, the enlargement of fissure aperture also increases. It seems with decreased length of fissure, weight reduction increases as fissure enlargement increases.

The relationship between variations of flow rate versus time for different width joint over the period of three months is shown in (Fig.4).

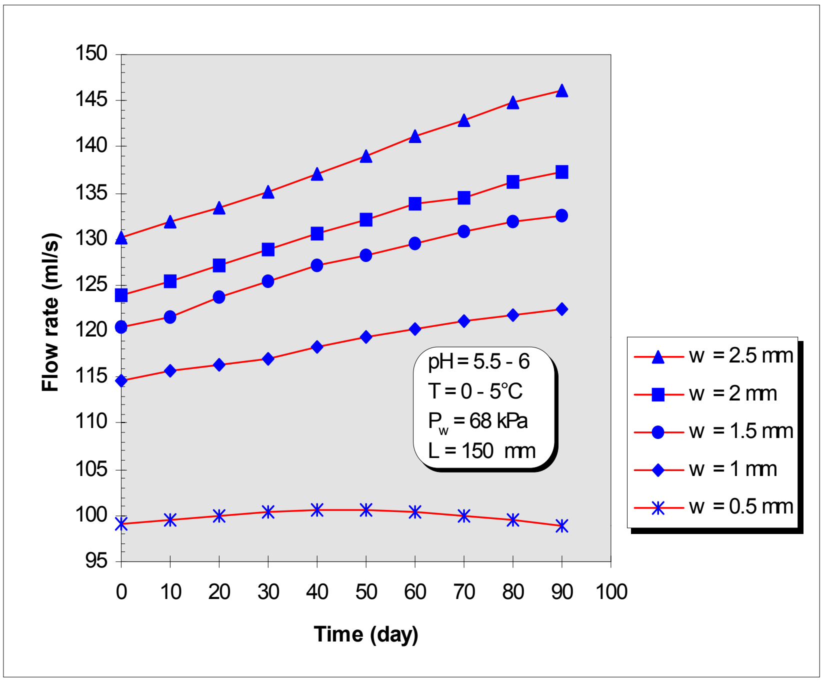

Fig. 4. Relationship between width of sample vs time over a 90 day period.

As this figure shows, from the analysis of the 50 tests performed, the fissure aperture of sample increases, the flow rate increase. E.g. the flow rate in sample to fissure aperture 0.5 mm after the period of three months decreases from 99.2 to 98.9 ml/s. The flow rate in sample to fissure aperture of 2.5 mm increases from 130.2 to 146.2 ml/s.

Summary of variation of flow rate and enlargement of fissures over the period of three months (different width joint) is shown in Table 3.

Table 3. Summary of variation of flow rate and enlargement of fissure over a period of three months (different width joint).

Sample No.	6	7	8	9	10
L = mm	150	150	150	150	150
D = mm	50	50	50	50	50
W = mm	0.5	1	1.5	2	2.5
Date	Q_{ave} ml/s	Q_{ave} Ml/s	Q_{ave} ml/s	Q_{ave} ml/s	Q_{ave} ml/s
3.7.2002	99.2	114.6	120.5	124.0	130.2
13.7. 2002	99.6	115.7	121.5	125.4	131.8
23.7. 2002	100	116.3	123.6	127.2	133.5
2.8. 2002	100.4	117.1	125.4	128.8	135.2
12.8. 2002	100.7	118.3	127.2	130.6	137.1
22.8. 2002	100.7	119.4	128.2	132.2	139.0
2.9. 2002	100.4	120.2	129.5	133.8	141.1
12.9. 2002	100	121.1	130.9	134.4	142.9
22.9. 2002	99.5	121.7	131.8	136.1	144.8
1.10. 2002	98.9	122.3	132.5	137.3	146.2
% $\Delta Q/Q_0$	-0.30	6.7	9.96	10.72	12.29
% $\Delta w/w_0$	-0.10	2.2	3.32	3.57	4.10
Enlargement of fissure (mm)	-0.001	0.022	0.033	0.036	0.041

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As this table shows, from the analysis of the 50 tests were performed, sample No. 6 (w = 0.5 mm, L =150 mm) indicates a -0.3% decrease in flow rate, sample No. 7 (w =1 mm, L = 150 mm) indicates a 6.7% increase in flow rate, sample No. 8 (w =1.5 mm, L = 150 mm) indicates a 9.96% increase in flow rate, sample No. 9(w = 2 mm, L= 150 mm) indicates a 10.72% increased in flow rate and sample No. 10 (w = 2.5 mm, L =150 mm) indicates a 12.29% increased in flow rate.

It seems with increasing fissure width, flow rate increases.

It can also be seen from the this figure and Table 3. that over a period of three month the result of fissure enlargement at different width is as follows:

Sample No. 6 to fissure aperture of 0.5 mm decreases to 0.499 mm, sample No. 7 to fissure aperture of 1 mm increases to 1.022 mm, sample No. 8 to fissure aperture of 1.5 mm increases to 1.537 mm, sample No. 9 to fissure aperture 2 mm increases to 2.036 mm and sample No. 10 to fissure aperture 2.5 mm increases to 2.541 mm. It seems with increased the fissure width, fissure enlargement increases.

A summary of variation of weight of rock samples at the period of three months is shown in Table 4.

Lmplication

1.The apparatus developed in this study, and the test method adopted, might be used as a method to study the solubility of rocks in practice and research.

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2.The laboratory results show that where the initial width of fissures is smaller than 0.5 mm, the width does not increase.

If the site investigation shows that the carbonate rocks at a site has fissures smaller than 0.5 mm, then the risk of solubility is low.

Table 4. Summary of variation of weight of rock samples at the period of three months (different width joint).

Sample No.	6	7	8	9	10
L = mm	150	150	150	150	150
D = mm	50	50	50	50	50
W = mm	0.5	1	1.5	2	3
Samples weight.(g) '1st day'	780.4	775	784.3	772.7	781.6
After 30 days (g)	771.4	763.4	770.8	759.5	767.1
After 45 days (g)	763.8	753.8	760.3	748.3	755.6
After 60 days (g)	759.8	744.9	755.3	743.3	750.6
After 75 days (g)	754.7	738.2	748.7	736.1	743.1
After 90 days (g)	751.2	733.2	740.3	727.9	735.0
% Weight reduction	3.74	5.39	5.61	5.80	5.96

Conclusions

The following general conclusions can be drawn from the study carried out as reported in this paper:

1. When fresh water moves through joints, the rate of solubility is very high at the beginning. This rate will decrease when the concentration of calcium in water increases.

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2.The flow rate through the fissure increases with time as the fissure enlarges.

3.The length of fissure decreases with increasing the flow rate.

4.The length of fissure increases with decreasing the flow velocity and decreasing head loss as fissure enlargement decreases.

5.The enlargement of fissure aperture increases with increasing weight reduction.

6.The length of fissure decrease with increasing weight reduction as fissure enlargement increases.

7.The width of fissure increases with increasing the flow rate as fissure enlargement increases.

8.The length of fissure decrease with increasing hydraulic gradient as fissure enlargement increases.

9.The fissures smaller than about 0.5 mm are unlikely to be dangerous in most foundations in carbonate rocks. An appropriate grouting programme can be designed for rocks containing large fissures.

References

1. M.H. Ghobadi, The influence of aperture of joints on solubility of carbonates rocks. International Symposium Engineering Geology and Environment, Athens, Greece(1977) pp. 127-131.
2. M.H. Ghobadi, The solubility of carbonate rocks and their effects on Kavar Dam foundation in Iran. First International Conference of sustainable development in karst regions. Beijing, China. Abstract(2001).
3. A.N. James, Solution parameters of carbonate rocks. Bull. Int. Assoc. Eng. Geol., No. 24 (1981)19-25.

4. A.N. James, Soluble material in Civil Engineering. Ellis Horwood, New York (1992)434.

5. A.N. James and I.M. Kirkpatrick, Design of foundations of dams containing soluble rocks and soils, Q.J. Eng. Geol., Vol. 13 (1980)189-198.

6. A.N. James and A.R.R. Lupton, Gypsum and anhydrite in foundations of hydraulic structures. Geotech., 28, No. 3(1978) 249-272.

7. H. Sadeghi, The geotechnical properties and effective parameters in the phenomena of solubility of limestone. BGS Young Geotechnical Engineer,s Symposium, Oxford, England(1996, April.) 109-110.

8. H. Sadeghi and F. Khosravi, A study of the effect of wave velocity on solubility of limestone. Paper presented at the 5th Iranian Tunnelling Conference, Tehran, Iran(2001, Oct.).

9. H. Sadeghi and F. Khosravi, The effect of mechanical properties on solubility of limestone. 9th International Congress Engineering Geology for Developing Countries(IAEG)Durban, South Africa(2002, September) 2277-2286.

[DOR: 20.1001.1.22286837.1382.1.2.4.7]