SOLUTION PARAMETERS OF CARBONATE ROCKS

PARAMETRES DE DISSOLUTION DES ROCHES CARBONATEES

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Abstract

Hydraulic structures founded on carbonate rocks can be endangered by progressive enlargement of fissures or the formation of solution cavities as aggressive (unsaturated) waters percolate through them. Previous literature describes how both the rate and manner of enlargement of fissures depend upon the solubilities and solution rate constants of soluble rocks. It has also been shown that the safe maximum size of fissures for a given hydraulic structure can be calculated from the solution parameters of the rock.

It has been suggested that carbonate rocks of various origins and types have very different solution properties, thus complicating site investigation procedures and the design of foundations. However, this paper describes the results of laboratory experiments on ten distinctly different specimens of carbonate rocks, which show that the solubilities and solution rate constants are all very similar. In pure water, solubilities of different carbonate rocks are virtually the same as pure calcium carbonate and solution rate constants are between 1.2 and 3.3 x 10^-5 m/s. These differences in solution rate constants are too small to be significant in engineering design.

The solution rate constants decrease by a factor of about ten when dissolved by water containing carbon dioxide in the concentration range 5 x 10^-4 to 3 x 10^-2 Moles/litre. However within this range of concentrations the rate constants are 1.8 to 2.7 x 10^-6 m/s.

In deciding how to safeguard the foundations of hydraulic structures in carbonate rocks against solution it is therefore not necessary to know the type or geological origin of the carbonate rock. However, to determine the solubility of the rocks the chemical composition of the inflowing seepage water must be known, also the sizes and distributions of fissures must be assessed by direct observations or by other methods such as water tests in boreholes.

The paper shows that fissures smaller than about 400 μm are unlikely to be dangerous in most foundations in carbonate rocks. An appropriate grouting programme can be designed for rocks containing large fissures.

Résumé

Des structures hydrauliques fondées sur des roches carbonatées peuvent être mises en danger par l'augmentation progressive des fissures ou la formation de cavités de dissolution si elles sont percolées par des eaux agressives. La littérature décrit comment le degré et le mode d'augmentation de la fissuration dépendent tous les deux de la solubilité et des constantes du taux de dissolution des roches solubles. On a montré aussi que la taille maximale des fissures pour la sécurité d'une structure hydraulique donnée peut être calculée à partir des paramètres de dissolution des roches.

On a indiqué que les roches carbonatées d'origines et de types différents ont des propriétés diverses; ceci complique les investigations et les projets de fondation. Cet essai décrit les résultats des expériences en laboratoire qui ont été effectuées sur dix spécimens de roches carbonatées très visiblement différentes. Ces expériences montrent que la solubilité et les constantes de dissolution sont toutes très semblables.

Les solubilités des différentes roches dans l'eau pure sont vraiment les mêmes que celles du carbonate pur de calcium. Les constantes de dissolution varient entre 1,2 et 3,3 x 10^-5 m/s. Ces différences des constantes de dissolution sont trop petites pour être significatives au sens de l'ingénieur.

La constante de dissolution décroît d'un facteur de dix, si la dissolution se fait par l'eau chargée en gaz carbonique, à une concentration de 5 x 10^-4 à 3 x 10^-2 moles/litre. Dans ces ordres de grandeur de concentration les constantes de dissolution varient de 1,8 à 2,7 x 10^-6 m/s.

Pour décider comment protéger les fondations des structures hydrauliques dans les roches carbonatées contre la dissolution, il n'est pas nécessaire de savoir le type ou l'origine géologique de la roche carbonatée. Toutefois, il est évident qu'on doit connaître la composition chimique de l'eau s'infiltrant pour déterminer la solubilité des roches. De même l'étendue et la distribution des fissures doivent être estimées par des observations directes ou par d'autres méthodes comme des tests d'eau dans les trous de forage.

L'article montre que les fissures de moins de 400 μm ne sont pas dangereuses pour la plupart des fondations sur les roches carbonatées. Un programme d'injections approprié aux roches qui contiennent de grande fissures.

Solution Parameters of Carbonate Rocks

Many hydraulic structures founded upon carbonate rocks are safe against solution attack because the impounded water or groundwater is already saturated with calcium carbonate before it reaches the structure. However, there are other cases, for example the Ilisu dam in Turkey, where this is not so and water seeping through foundations, drains and filters, may be unsaturated and therefore capable of dissolving the carbonate rock materials. For example, snow melt water in flood conditions is often an aggressive agency.

The solution of limestone by percolating groundwater to form caves and enlarged fissures is well known and has been of particular interest to speleologists and geologists. Numerous papers and books have been published, for example by Ingle Smith (1974), and Trudgill (1977) who described aspects of the solution process which occurs in the shorter term. The different weathering aspects of limestones have been discussed by Sweeting and Sweeting (1969). Chemical equilibria of the system calcium carbonate, water and carbon dioxide have also been the subject of many publications, but a useful collection of data and relationships has been published by Picknett (1973). The engineering consequences of karstic formations in limestones has been reviewed by Martinez (1969) particularly in the context of dam construction. These references are not comprehensive but act as a guide to a fuller bibliography.

Despite the considerable body of literature describing various aspects of the solution of carbonate minerals by water and carbon dioxide, there has been no published account, as far as the author is aware, of quantitative methods of design which take account of the rate of solution of limestone and other carbonate rocks in hydraulic structures.

For design purposes it is required to know the solution characteristics of the rock, i.e., solubility and solution rate constant and the composition and temperature of the groundwater. They may then be combined with anticipated seepage flow velocities through the relevant components of the structure and foundations to provide an estimate of the rates of solution and how they affect its service life. Theory and methods of calculation have been described by James and Lupton (1978).

The solution characteristics of one sample of a limestone (Portland Stone) have been previously described by James and Kirkpatrick (1980), but the same characteristics of a wider variety of naturally occurring calcium (and magnesite) carbonate minerals were not then available. It is reasonable, on chemical grounds, to suppose that the shared and characteristic chemical components calcium carbonate would give all the minerals the same or very similar solution rate constants and solubilities, but geologists in various discussions with the author have expressed their doubts. It was therefore important to resolve this matter. If all carbonate rocks could be said to have virtually the same solution rate constants and solubilities, then the author is aware of quantitative methods of design which take account of the rate of solution of limestone and other carbonate rocks in hydraulic structures.

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A further issue concerns the effect which acid waters containing free carbon dioxide, have upon the solution rate constants. As a working hypothesis it had been assumed that they would be unaffected, but that the solubilities would increase according to the data published by Weyl (1959).

This present paper describes the measurements of solution rate constants (K) in pure water of a series of ten different but well characterised carbonate rocks. Also the solution rate constants of one of this series of samples have been measured in solutions of varying carbon dioxide content. Finally the solubilities of a selection of the series of rock samples were measured in solutions of carbonic acid.

Experimental Design

Before starting the laboratory programme it was necessary to know the effect of inaccuracies in the measurements upon engineering design and an assessment of these effects was made in terms of the way fissures enlarge as aggressive water flows through them. Predictive methods have been described previously by James and Lupton (1978).

A period of 200 years was chosen as typical of the design life of a dam and 2,000 years as indicative of a period of geological weathering or special engineering applications such as the underground storage of radioactive waste.

The first example considered was a relatively large fissure 1 mm wide which would be capable of providing substantial seepage flow. It was chosen to illustrate the effect of changing values of K upon the enlargement of fissures by solution processes. The fissure was taken to be 100 m long and subject to an hydraulic gradient of 0.2; it was further assumed that water entering the fissure could dissolve 50 mg/litre of calcium carbonate. We first use the values of K (which are dependent on flow velocity) taken from Fig. 2 of the paper by James and Kirkpatrick (1980). Note that these values are not necessarily those of an aggressive water dissolving calcium carbonate but are used here to serve the example.

The fissure would then enlarge over a period of 200 years according to curve B, Fig. 1. A set of K values three times greater produces a fissure enlarged according to curve A, Fig. 1. The worst result from an engineering point of view is shown in curve B corresponding to the lower values of K. The fissure has become long and tapered; it has enlarged slightly at its outlet as well as its inlet; flow rates have increased and the whole solution process is accelerating rapidly. This is because water has to travel a greater distance along the fissure before it becomes saturated.

Curve A, corresponding to the set of higher values of K, shows considerable loss of calcium carbonate at the inlet but the fissure is not enlarged near the outlet. The flow rates have only changed by a relatively small factor. The solution process is accelerating very slowly.

After 2,000 years it may be seen from the curves C & D in Fig. 1 that both sets of values of K have caused massive enlargements and loss of calcium carbonate. However, the flow rates caused by using the set of smaller values of K (curve D) are much greater.