Major Problem at Micro Level : Alkali-aggregate Reaction and its effect on Srisailam Dam, Andhra Pradesh, India

M. Raju* and B. Satyanarayana**

Abstract

A chemical reaction between alkali content in the Portland cement and part of reactive silica present in aggregate, popularly known as alkali-silica reaction, gained importance because of serious damages to many concrete structures attributed to this phenomenon. An expanding silica gel is product of the reaction causing increase in volume and thereby leading to stresses in concrete which ultimately result in cracks. Reaction takes place in no definite period and time, contributing factors are ascribed to many parameters like mineral of aggregate, pH condition of soaking water, temperature etc.

The problem is discussed with particular reference to the 30 year old Srisailam dam in Andhra Pradesh, India, where the petrographic study of aggregate and concrete samples indicates the presence of material that has potential to create alkali-aggregate reaction. But no deleterious effects such as reaction haloes, are noticed in the concrete samples. The reaction has not commenced despite the presence of deleterious materials and the time elapsed after construction of dam. However, as there is no known time limit for the reaction to initiate, it is opined that it warrants necessary precautionary measures.

Introduction

The alkali-silica reaction consists of a reaction between the alkali contained in the cement and the reactive silica present in the aggregate. In certain cases, an expanding silica gel is formed, which causes an increase in volume and therefore high stresses within the concrete, which ultimately cause crakes (Brown, 1955). The reaction can take place over a period of time between a few months to several years and it is affected by various parameters, such as, temperature, soaking conditions, the presence of other aggressive minerals or acidic water, absolute and relative percentages of alkali and silica present in the concrete. The available data indicate that the following factors are contributing to damaging levels of alkali-silica reaction, such as, (i) presence of Na_2O and K_2O equivalent above 0.6 to 0.8%; (ii) aggregate containing silica in a reactive form (opal, flint, jasper, chalcedony, quartz with strong undulatory extinction) in percentages above 0.6 to 1 ; (iii) presence of carbonate rocks in the aggregate; (iv) presence of humidity in the concrete. These and various other parameters influence the amount and time of the reaction (Gogte. 1973).

Performance of a number of dams and other hydraulic structures were affected by the alkali-aggregate reaction. Once the reaction triggers, there is no definite way of preventing damage caused by the reaction or to arrest the growth of alkali-silica reaction triggered in the concrete, and in a few cases it ultimately lead to abandonment of the structures. In India, there are reports of distress in two dams, viz., Hirakud dam in Orissa and Rihand dam in Uttar Pradesh, attributed to the alkali-aggregate reaction. It was reported after a period of 18 years of construction in case of former one and in case of the latter, the distress was noticed since commissioning of the dam (Aggrawal, *et.al.*, 1985; Patri, *et.al.*, 1985). It clearly indicates that the alkali-aggregate reaction can start at any time after the construction.

*Director, Engineering Geology Division, Geological Survey of India, S.R., Hyderabad.
**Director, Vigilance Cell, Geological Survey of India, CHQ, Kolkata.

Preventive measures

As there are no definite ways to arrest the reaction once it is commenced, it is better to adopt preventive measures. Preventive measure are, (i) avoiding the aggregates containing vulnerable mineral constituents as mentioned above, and use of aggregates that are not alkali-reactive in concrete, (ii) use of Portland cement with low alkalis, having alkali content 0.6% Na_2O equivalent by weight; use of Portland blast furnace cement or Portland cement mixed with ground granulated blast furnace slag; use of Portland fly ash cement or Portland cement mixed with fly ash with not less than 25% of the cement replaced by fly ash (ACI 225 (R) 1985), and (iii) preventing contact between concrete and any external source of moisture. Concrete should be designed dense with low permeability in order to minimize ingress of outside moisture.

Strained quartz

Quartz is among the hard and durable minerals available as regards the physical and engineering properties. However strained quartz is more susceptible to alkali-aggregate reaction (Gogte, 1973). The orientation of optic axis in plastically deformed (strained) quartz crystals differs by a few degrees in different parts of a single crystal. This results in development of wavy extinction in quartz which is common in deformed rocks. The presence of such strained quartz showing wavy extinction is capable of bringing about deleterious alkali-silica reaction, though at a much slower rate. Though no definite standards are available to determine reactivity of strained quartz and the associated deleterious expansion, it is considered in general that the coarse aggregates containing 40% or more strongly undulating fractured or highly granulated quartz are 'highly reactive', those with 30 to 35% of strained quartz are 'moderately reactive', and the presence of strained quartz more than 20% with an average wavy extinction angle of more than 15° is considered to be potentially reactive. The rocks with predominantly unstrained or recrystallised quartz are considered 'innocuous' (Sudhindra et.al., 1987)

Srisailam dam

Srisailam hydroelectric project, recently renamed as Neelam Sanjeeva Reddy Sagar Project was constructed across the River Krishna near Srisailam in Andhra Pradesh. The project consists of a gravity dam with a storage reservoir (8734 million cubic metres capacity), a 770 MW hydroelectric power station on the right flank and a 900 MW underground hydroelectric power station on the left flank. The dam is 512 m long, 143 m high gravity structure, consisting of flip bucket type spillway of 12 bays. A little part of the dam was constructed with stone masonry and the rest with cement concrete. The construction of the dam was started in 1974 and completed in 1980. Filling of the reservoir was started in 1980 and the reservoir was impounded up to full reservoir level of 269.75 m during the year 1984 for the first time.

The area exposed the rocks of Srisailam Formation of Cuddapah Super Group of Proterozoic age. Igalpenta Quartzite and Tapasipenta Siltstone of Srisailam Formation are the two Members exposed at project site. Flat bedded and jointed quartzites with thin layers of interbedded shales are prominent rock types over which the dam was built (Raju and Thanavelu, 1991; Raju *et. al.*, 1993; Raju, 1995; Raju and Kumar,1997; Raju,1999).

Petrography of rock samples

There are a few methods of tests for determining the potential reactivity of aggregates, such as, Mortar Bar Method, Chemical Method (IS 2386:Part-VII-1963) and petrographic examination of rock samples. Among them petrographic examination is considered more acceptable. Petrographic study of representative rock samples, collected from all over the effected area is essential to ascertain the alkali-silica reactivity (Barisone, 1984). Three rock samples were collected from Karikelavagu near Srisailam, where quarry site of Srisailam project was located, and petrographic study of the samples were carried out with regard to their alkali-aggregate reactivity. The study indicates the presence of strained quartz in the rock samples in the range of 42.6% to 58.2%, which is considered on the higher side. The undulatory extinction angle of the strained quartz is reported to be 25° to 35°. This feature is also considered to be highly susceptible to alkali-aggregate reaction. Up to 0.6% of chert, yet another silicate susceptible to alkali-aggregate reaction, was found in the model composition of the three rock samples. Carbonate cement and quartz over growths reported in the thin sections of rock samples are products of diagenesis, which is also not a good feature for an aggregate. It also contributes to alkali-aggregate reaction. A model composition of aggregate sample is given in Table-1.

Chemical analysis of water samples

Water is required for expansion in alkali-aggregate reactions and tests have shown that potentially highly expansive concrete and mortar specimens, stored at low relative humidity, show little or no expansion. When water is made available the same specimens often expand rapidly. This result is to be anticipated since all mechanisms of expansion which have been proposed involve moisture uptake by the concrete. Hence, the exposure condition of concrete is also important consideration in assessing the potential alkali-aggregate reaction (Gellott, J.E., 1986). Besides, the acidity of water in contact with the concrete also effects the alkali-aggregate reaction. Srisailam reservoir water was also tested to know its nature and effect on the concrete in contact it. Analysis indicates the pH value of reservoir water on alkaline side. However, it is not proper to consider that the waters will always maintain similar values. There could be variation of pH value which has to be ascertained periodically.

The water analysis is indicated in the Table-2. The pH value of reservoir water is 7.9, whereas that of seepage water from gallery of the dam is 8.1. This increase could be due to the increase in total dissolved salts acquired by reservoir water during its passage through the concrete of the dam. Similarly, the specific conductivity of water in gallery is 503 microhms/cm, as compared to 380 microhms/cm of reservoir water. This reflects increase in the total dissolved salts. There is also an increase in bi-carbonates, calcium and magnesium in the water collected from the gallery. The total hardness also is higher

Table 1: Model composition of aggregate samples.

S.No.	Constituent mineral	Sample 1	Sample 2	Sample 3
1.	Monocrystalline quartz – undulatory	42.6	55.8	58.2
2.	Monocrystalline quartz – nonundulatory	9.3	8.4	4.1
3.	Poly crystalline quartz	4.9	4.1	5.1
4.	K-feldspar	3.6	6.0	3.7
5.	Plagioclase	0.1	0.2	1.2
6.	Rock fragments	0.4	-	-
7.	Chert	-	0.5	0.6
8.	Silica cement as			
	overgrowth	3.5	2.7	8.0
9.	Carbonate as cement	35.3	21.3	17.6
10.	Opaques	0.2	1.0	1.5

(Tests carried out by the Petrology Division, Geological Survey of India, S.R., Hyderabad)

Table 2: Chemical analysis of water samples:

S. No.	Component	Seepage water from gallery	Reservoir water	Seepage water from left bank	ISI 10500-1983
1.	pH	8.1	7.9	7.7	6.5 – 8.5
2.	Specific conductance (micro ohms/cm)	503	380	447	
3.	CO_3^{-2}(mg/l)	Nil	Nil	Nil	
4.	HCO_3^-(mg/l)	192	168	186	
5.	Cl^-(mg/l)	43	39	48	250
6.	Total hardness as $CaCO_3$(mg/l)	175	120	130	960
7.	Ca^{+2}(mg/l)	44	32	38	
8.	Mg^{+2}(mg/l)	16	10	9	
9.	TDS (mg/l)	296	226	272	500
10.	SO_4^-(mg/l)	23	35	47	
11.	Na^+(mg/l)	48	41	45	
12.	K^+(mg/l)	4	3	3	

(Tests carried out by the Chemical Division, Geological Survey of India, S.R., Hyderabad.

(175 mg/l of water collected from gallery as compared to 120 mg/l of the reservoir water). Analysis, therefore, indicates that the water when passing through concrete dam acquired some of these elements, though these are considered to be very insignificant.

Petrography of concrete samples

Petrography of 3 concrete samples collected from 11th vent of the spillway of Srisailam Dam, which was placed in the month of January, 1977 was carried out. Collection of samples and their petrographic examination was carried out in the year 1990. These samples were reported to be casted in cylinders at the time of placement for testing of compressive strength. The concrete samples consist of similar rock as that of the studied coarse aggregate (Table-1), but do not show any reaction haloes under petrographic microscope. As there is no visual manifestation of distress in the dam body, this condition is considered applicable even now, after completion of 30 years of life of dam. The nature of cement used in Srisailam Dam and its alkali content is not known.

Conclusions

Rocks with deleterious minerals susceptible to alkali-aggregate reaction should be avoided as aggregate. If it is unavoidable to use such aggregate, it is advisable to use Portland cement which contains fewer alkalis to minimize the reaction.

The petrographic study of 3 rock samples and 3 concrete samples of the Srisailam project indicate that though the samples satisfy most of the requirements to initiate alkali-aggregate reaction, no such deleterious reaction is indicated by the petrography of concrete sample. However, there is no time limit for an alkali-aggregate reaction to commence.

There is necessity of periodic petrographic study of concrete used for the dam, especially which is in constant touch with the reservoir water, in order to monitor alkali-aggregate reaction. Simultaneously, any distress noticed in the concrete should also be assessed.

Further, the contact of reservoir water with the dam concrete may be minimized. The upstream face of the dam body which comes in contact with the reservoir water, may be applied with water proof paint. The drainage holes within the dam body are to be regularly cleaned, to facilitate free drainage and to avoid saturation of dam body, as far as possible. It is also necessary to regularly monitor pH of reservoir water and to maintain its alkalinity.

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