

MANAGING ALKALI-AGGREGATE REACTION EXPANSION IN MASS CONCRETE

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Introduction

When the alkalis in cement react with susceptible aggregate particles, a reaction rim of alkali-silica or alkali-carbonate gel is formed around the aggregate. If this gel is exposed to moisture, it expands, causing an increase in volume of the concrete mass. This expansion will develop if the relative humidity (RH) in concrete is higher than 80 to 85% and temperature is 50 to 104°F (10 to 40°C). Alkali-aggregate reaction (AAR) in mass concrete sections typically results in extensive cracking with crack widths that can be much wider compared with cracking caused by other types of deterioration (Fig. 1). The crack width can range from 0.004 in. (0.1 mm) to as much as 0.4 in. (10 mm) in extreme cases. The severity of cracking appears to be a function of the rate of internal expansion, ambient environmental conditions, and the degree of restraint present in a given concrete section. Cracking in large mass concrete structures can be unsightly, although structural integrity may or may not be impaired. Expansion of the concrete can cause major operation and maintenance problems, such as inoperable gates in locks and dams and misalignment of hydropower generators in dams.

While the causes of AAR and maintenance issues may be applicable to other types of concrete structures, the discussion is often directed toward mass concrete structures. Mass concrete is the volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat and temperature gradients from hydration of the cementitious materials and attendant volume change due to internal or external restraint.

Question

What are the maintenance and repair techniques for mass concrete structures damaged by AAR?

Answer

There is no universal approach to maintenance or repair of concrete structures affected by AAR, and problems usually are addressed on a case-by-case basis. Maintenance and repair ranges from monitoring the AAR-affected concrete (Fig. 2) to complete removal and replacement.

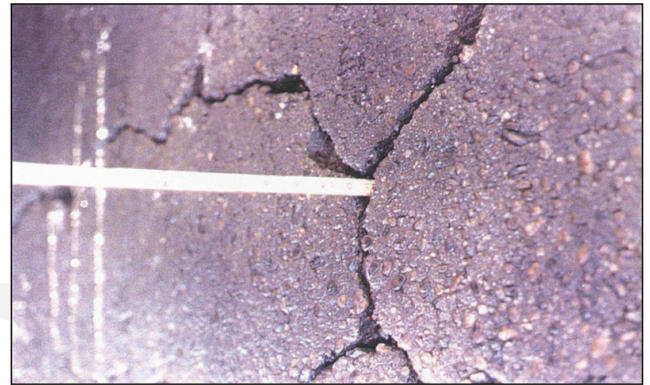


Fig. 1—Wide cracks in concrete as a result of AAR (width of the order of 1 in. [25 mm] in certain areas).



Fig. 2—Monitoring changes in crack width.

Discussion

Most research is directed at investigating mechanisms of deterioration, identifying materials susceptible to reaction, and preventing AAR (201.2R; 221.1R) in new construction. In theory, drying the concrete is the most judicious way to mitigate the expansion process in an existing structure; however, in practice, the size of mass concrete structures makes it nearly impossible to completely dry the concrete sufficiently to mitigate the AAR reaction (201.2R; 221.1R). If the concrete cannot be dried, then applications of surface treatments, such as penetrating sealers and thin coatings, can be used to minimize the ingress of moisture. This will, at best, maintain the moisture content present in the concrete at the time of treatment. The moisture content in the interior of mass concrete will almost always be above the threshold value required for expansive activity. For example, results of tests on five dams in the desert southwestern United States show that atmospheric drying has little or no effect on the internal RH and moisture content of concrete. Even after 50 years of exposure, values for RH exceeded the 85% threshold for expansion as little as 0.5 to 1 in. (12 to 25 mm) from exposed surfaces (Stark and DePuy 1987). Therefore, application of surface treatments should not be expected to mitigate expansive activity in mass concrete and, in some cases, it actually may increase the moisture content of the concrete by preventing migration of moisture through the concrete surface.



Fig. 3—Crack repair by epoxy pressure injection.

Because AAR in mass concrete sections typically results in extensive wide cracking, sealing the cracks by epoxy injection may be the most obvious repair action (Fig. 3). While crack injection may increase structural stability and minimize ingress of external contaminants, it will also block egress of reaction products, potentially increasing the pressure from internal gel expansion and enhancing the formation of new cracks. Injection with flexible materials may provide some improvement in repair performance. Consider crack sealing and injection only after a careful evaluation of its compatibility with future expansive reactivity.

The chances for successful repair of a mass concrete structure where the concrete exhibits continuing AAR expansion are very low. Such structures can often continue in operation for extended periods, provided appropriate maintenance programs are implemented. The most common remedial action to keep mass concrete structures in service (Fig. 4) is opening joints or cutting slots by sawing to relieve internal stresses. In this process, a continuous loop of wire embedded with cutting diamonds makes the desired cut. Some dams have been post-tensioned before slot-cutting to prevent excessive shear at the slots as the stress was relieved and to improve earthquake resistance (Newell and Wagner 1995).

One of the first applications of diamond wire technology to cut slots in a mass concrete structure was in the intake structure at Mactaquac Generating Station (Thompson 1990). Waterstops were installed in the open slots to control leakage. Diamond-wire cutting has also been used successfully to reestablish or widen contraction joints in several mass concrete structures. The first application of diamond wire technology for cutting slots in a powerhouse began in 1993 at R. H. Saunders Generating Station (Kee et al. 1998). The cuts were made in critical areas of monolith joints (80 ft [24.3 m] wide and 80 ft high [24.3 m]) between generators. The closed joints that were originally 0.2 in. (5 mm) wide were enlarged to 0.6 in. (15 mm). The concrete expanded by 0.2 in. (5 mm) almost immediately after the slots were cut, and the concrete expanded another 0.2 in. (5 mm) during the next year. Subsequent expansion was at a rate of approximately 0.04 in. (1 mm) per year. New slots will be cut as necessary to relieve stress and accommodate future growth in the concrete, a process that will be easier in the future because of the availability of existing access holes.

Expansion of the concrete at Center Hill Dam resulted in binding of the spillway gates and closing of the expansion joints in bridge spans over the spillway. AAR expansion occurred for approximately 40 years before it was necessary to alter the structure to maintain operational capability. The bridge spans were shortened in 1985 by cutting the concrete deck and steel girders. The supports and expansion joints were also reset (Hugenberg and Hull 1995). Two gates were shortened, and the gate seal plates embedded in two monoliths were built out to vertical so that the gates were again functional. Binding of one of the modified gates necessitated additional shortening of the gate and modification of the seal plates in 1991. Modifications of the bridge spans and spillway gates are recognized as nonpermanent solutions to operational deficiencies in a structure that is exhibiting